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Barbers Point Harbor Physical Model Navigation Study

Gordon S. Harkins, Cecil C. Dorrell

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Preface

This study was authorized by the U.S. Army Engineer Division, Pacific Ocean (POD), and was conducted by personnel of the U.S. Army Engineer Research and Development Center (ERDC) Coastal and Hydraulics Laboratory (CHL), Vicksburg, MS. This former POD office has since been restructured as the U.S. Army Engineer District, Honolulu, one of the three districts which now compose the present POD. The study was conducted during the period November 1997 through March 1998.

Ms. Helen Stupplebeen and Mr. Stanley Boc, POD, and Mr. Fred Nunes, Harbors Division, State of Hawaii Department of Transportation, provided technical oversight of the physical model study, reviewed model test results, and made pertinent recommendations pertaining to critical experiments and data analysis. Harbor pilot David Lyman provided valuable insight regarding ship maneuvering aspects of the harbor modifications.

This study was conducted by Messrs. Gordon S. Harkins, Francis E. Sargent, and Cecil C. Dorrell, and Ms. Leonette Thomas, Harbors and Entrances Branch (HEB), Navigation and Harbors Division (NHD), CHL; Mr. Johnny Heggins, Coastal Structures Branch, NHD; Mr. David Daily, Instrumentation Services Division, Information Technology Laboratory, ERDC; and Mr. Danny Marshall, Mevatech Corporation. The main text of this report and Appendixes A through F were written by Messrs. Harkins and Dorrell. Appendix G was written by Dr. Edward F. Thompson and Messrs. Michael J. Briggs and Doyle L. Jones, Coastal Hydrodynamics Branch, NHD. Appendix H was written by Dr. Thompson and Mr. Jones.

The work was performed under the direct supervision of Mr. Dennis G. Markle, Chief, HEB, and Mr. C. E. Chatham, Chief, NHD. General supervision was provided by Mr. Charles C. Calhoun, Jr. (retired), former Assistant Director, CHL; and Dr. James R. Houston, Director, CHL.

At the time of publication of this report, Dr. Lewis E. Link was Acting Director of ERDC, and COL Robin R. Cababa, EN, was Commander.

1 Introduction

Description of Harbor

Barbers Point Harbor, Hawaii, is located on the southwest coastline of the island of Oahu (Figure 1). Figure 2 shows the present harbor complex (subsequently referred to as Plan 1a), consisting of an entrance channel, deep-draft harbor, barge basin, and a private resort marina (often referred to as the West Beach Marina). The entrance channel is 140 m (450 ft) wide, 945 m (3,100 ft) long, and 13 m (42 ft) deep, referenced to mean lower low water (mllw). The deep-draft harbor basin is 12 m (38 ft) deep, 700 m (2,300 ft) wide, and 640 m (2,100 ft) long, covering an area of 0.37 sq km (92 acres). Rubble-mound wave absorbers line approximately 1,128 m (3,700 ft) of the inner shoreline of the harbor basin. The barge basin, located just seaward of the harbor on the south side of the entrance channel, has little shelter from incident wave energy. It is 67 m (220 ft) wide, 396 m (1,300 ft) long, and 7 m (23 ft) deep. West Beach Marina was built on the west side of the deep-draft harbor. It shares the same entrance channel with the harbor, is 4.6 m (15 ft) deep, and covers approximately 0.08 sq km (20 acres). The marina was designed to accommodate 350 to 500 pleasure boats.

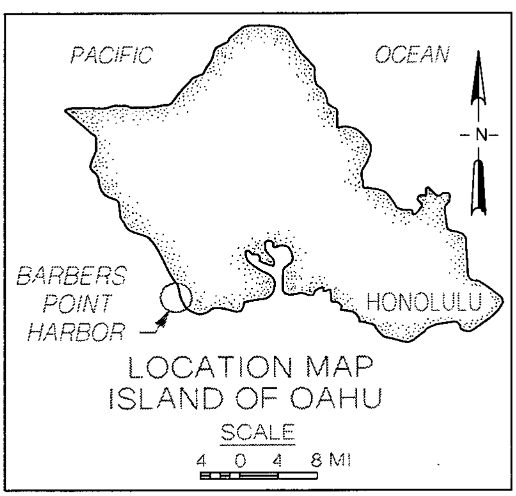

Figure 1. Project location

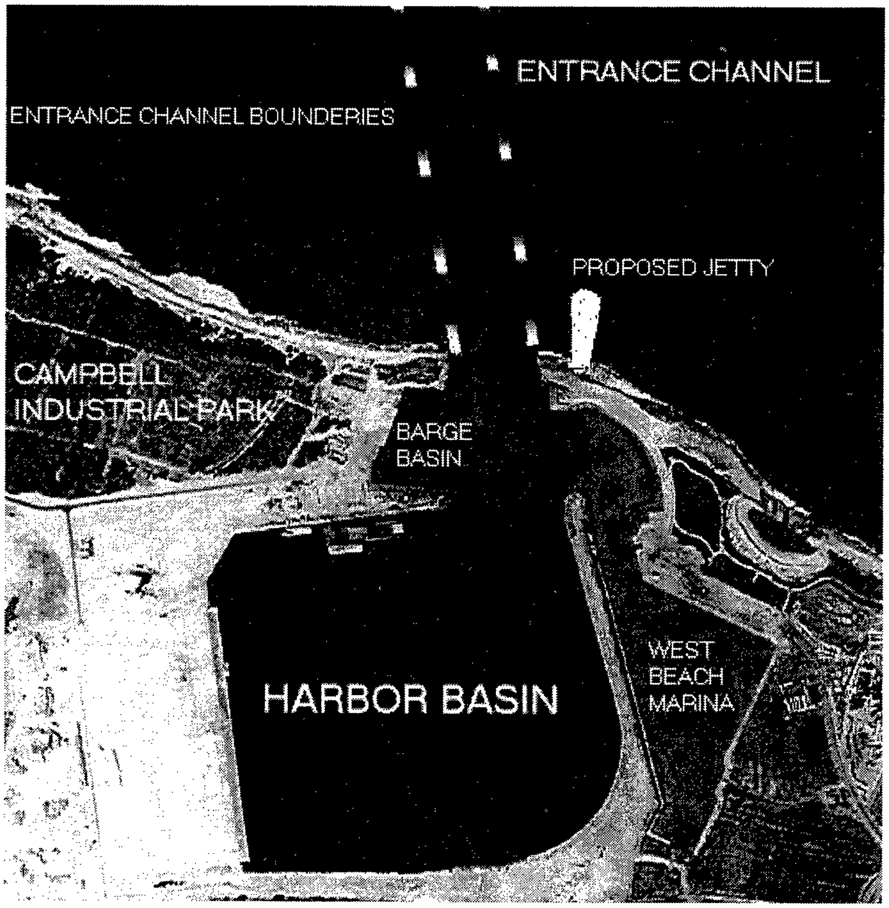

Figure 2. Aerial photograph of Barbers Point Harbor, Oahu, Hawaii

Background

Construction of Barbers Point Harbor was initiated in March 1982 and completed in December 1982 at a total cost of $47.2 million. Six years later, on behalf of the State of Hawaii, the U.S. Army Engineer District, Honolulu, authorized an assessment of the engineering feasibility, costs, and physical requirements for potential future modifications of Barbers Point Harbor to service vessels larger than the design vessel for which the harbor was originally constructed. Barbers Point Harbor was originally designed to accommodate a Matson Navigation Line (MNL) Enterprise-class general-cargo vessel with the following dimensions:

Length = 219 m (720 ft)
Beam = 29 m (95 ft)
Loaded draft = 10.4 m (34 ft)

General-cargo vessels dominated shipping in Hawaii in the 1960s; however, offloading of such vessels was very inefficient. Competition caused companies

to move towards larger vessels that can be more quickly offloaded, such as containerships and roll-on/roll-off vessels (e.g., car-carriers).[1]

Current and potential future users of the harbor would like the capability for fully loaded vessels to enter and leave the harbor, but safe vessel draft is restricted by existing harbor and entrance-channel depths. Numerical simulations of Barbers Point Harbor were conducted in 1988 using an American President Line (APL) C8-class containership with the following dimensions:

Length = 240 m (787 ft)
Beam = 30.5 m (100 ft)
Loaded draft = 10.7 m (35 ft)

That study indicated a C8-class containership could safely enter the harbor under ideal conditions (daytime, no waves, no current) with tug assistance.

The U.S. Army Engineer Division, Pacific Ocean (POD), and the Hawaii Department of Transportation (HDOT), Harbors Division, sponsored a navigation study of Barbers Point Harbor at the U.S. Army Engineer Waterways Experiment Station (WES) between 1990 and 1992.[2] Numerical and physical model studies of harbor response to modifications to the entrance channel and harbor geometry were conducted. Physical model navigation experiments with an APL C9-class containership were also conducted. The study recommendations included deepening the harbor from 11.6 m (38 ft) to 13.7 m (45 ft), deepening the entrance channel from 12.8 m (42 ft) to 14.9 m (49 ft), and widening the outer 305 m (1,000 ft) of the entrance channel from 137 m (450 ft) to 228 m (750 ft).

Table 1 shows the increasing size of the design vessels used in previous studies and the size of the design vessels used in the present model study. The length of the design vessel has increased approximately 20 percent while the draft has increased over 30 percent. It is more economical to the shipping companies if fully loaded vessels enter and leave the harbor. However, for a vessel to enter and leave the harbor, there must be a safe distance between the bottom of the vessel keel and the ocean bottom (underkeel clearance). The fully loaded design vessels used in this present study could not enter and leave the now-existing harbor configuration safely. The components of underkeel clearance are shown in Figure 3. Although all components of underkeel clearance are shown, only wave response and squat allowance were addressed in this study. Changes in water density would not be applicable to this project.

Differences exist between the State HDOT and the Corps POD underkeel clearance criteria. Presently, the State HDOT is using a 0.6-m (2-ft) underkeel

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[1] Permanent International Association of Navigation Congresses (PIANC). (1987). "Development of Modern Marine Terminal," Supplement to Bulletin No. 56, Brussels, Belgium.
[2] Briggs, M., Lillycrop, L., Harkins, G., Thompson, E., and Green, D. (1994). "Physical and numerical model studies of Barbers Point Harbor," Technical Report CERC-94-14, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Table 1
Summary of Design Vessels Used in Previous and Present Studies

Description	Length, m (ft)	Beam, m (ft)	Fully Loaded Draft, m (ft)	Date of Study
MNL Enterprise-class vessel	219 (720)	29 (95)	10.4 (34)	1963
APL C8-class containership	240 (787)	30 (100)	10.7 (35)	1988
APL C9-class containership	262 (860)	32 (106)	11.9 (39)	1990
Present study: modified Bunga Saga Empat bulk-cargo carrier and APL C9-class containership	259 (850)	32 (106)	13.7 (45)	Present study 1997

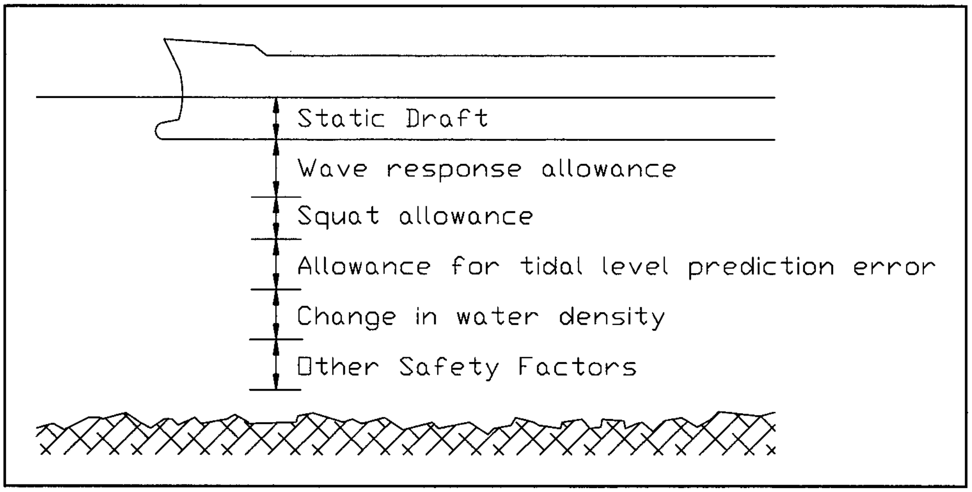

Figure 3. Components of underkeel clearance

clearance criterion in the harbor that translates to a 1.8-m (6-ft) underkeel clearance in the channel. The Corps POD criterion is more conservative, calling for a 1.2-m (4-ft) and 2.4-m (8-ft) underkeel clearance in the harbor and entrance channel, respectively. The underkeel clearance is shown graphically in Figure 4 for both the State HDOT and the Corps POD criteria.

Study Objectives

Objectives of this study include, for specific design vessels, a determination of the optimum vessel draft/entrance-channel depth combination that can safely transit the entrance channel and harbor. To determine the optimum vessel draft/entrance-channel depth combination, two design vessels were chosen: (a) a bulk-cargo vessel with a "box" shape (modified Bunga Saga Empat) and (b) a retrofitted sleeker vessel that had been used in the 1990 study (APL C9-class containership) (Table 1). Simulation of these vessels' transit through the entrance channel was made with selected wave conditions, and the underkeel clearance was measured. Results of the underkeel clearance criteria data for determining the optimum vessel draft/entrance-channel depth combinations are presented in Appendixes A through F.

Subsequent to the completion of the physical model navigation study described above for determining the optimum vessel draft/entrance-channel depth combination, POD requested WES to conduct numerical investigations that would (a) analyze impacts of the north jetty on wave climate in the barge basin and (b) document harbor-oscillation characteristics for entrance channel and harbor depths of 13.4 m (44 ft) and 12.8 m (42 ft), respectively, and 14.3 m (47 ft) and 13.7 m (45 ft), respectively, for a planned harbor expansion to 183 m (600 ft) wide and 335 m (1,100 ft) long. Results of these additional supplemental numerical investigations to (a) analyze impacts of the north jetty on wave climate in the barge basin and (b) document harbor-oscillation characteristics are presented in Appendixes G and H, respectively.

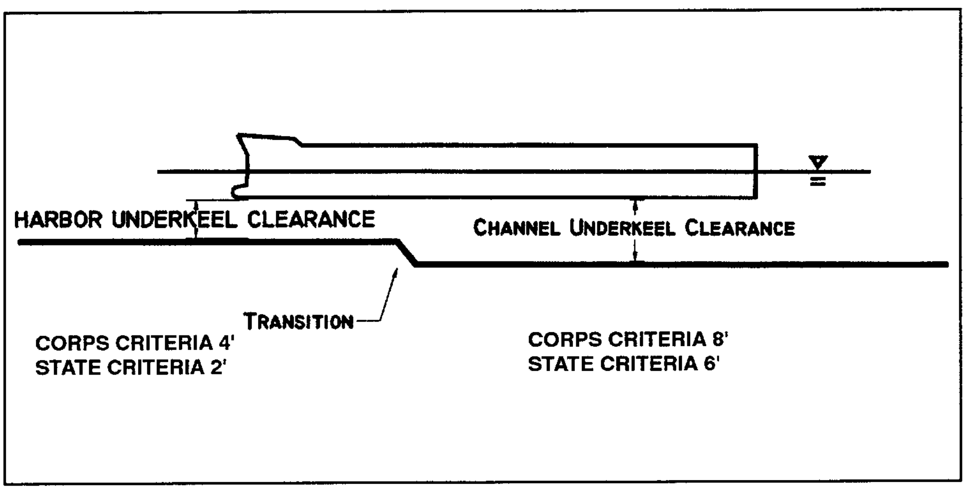

Figure 4. State HDOT and Corps POD underkeel clearance criteria shown graphically

2 Physical Model

This chapter describes equipment and techniques employed in the physical model to reproduce prototype conditions at Barbers Point Harbor. Model scaling laws were used to ensure similarity between the prototype and model for both the harbor and required vessels. The following equipment was utilized to reproduce and verify that the proper incident wave conditions were simulated in the model: a wavemaker to generate selected incident waves and wave gauges to ensure that the proper wave heights were being generated. A high-resolution video-tracking system was used to record vessel motions during transits both into and out of the harbor.

Model Design

An undistorted, three-dimensional model of Barbers Point Harbor (Figure 5) was constructed in 1991 at a model to prototype scale L_r = 1:75, in accordance with well-known Froude scaling laws. The nearshore area extends to the 30.5-m (100-ft) mllw contour and includes approximately 1 km (3,500 ft) on either side of the entrance channel. Total area of the model is over 1,000 sq m (11,000 ft^2). This model scale was selected to allow proper reproduction of significant harbor features. Model and prototype lengths scale as L_r, areas scale as L_r^2, and time and velocity scale as $\sqrt{L_r}$. Details of the model design can be found in Briggs et al. (1994).[1]

Model Appurtenances

Wavemaker

At slow vessel speeds, the principal component of underkeel clearance is the wave-induced vessel response. To simulate realistic wave conditions found at Barbers Point, waves were generated with a plunger wavemaker that is capable

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[2] Briggs, M., Lillycrop, L., Harkins, G., Thompson, E., and Green, D. (1994). "Physical and numerical model studies of Barbers Point Harbor," Technical Report CERC-94-14, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

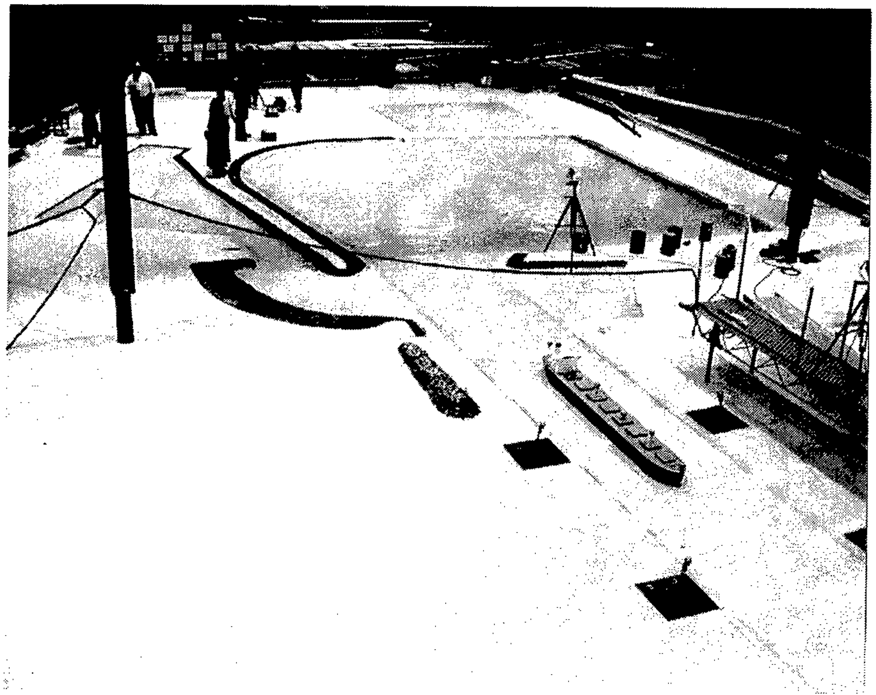

Figure 5. Barbers Point Harbor physical model

of generating irregular, unidirectional wave conditions. It is called a "plunger" wave machine because the wave board is constructed in the shape of a trapezoid and is plunged into the water column. The shape of the wave paddle is shown in Figure 6.

Simulating the appropriate wave conditions is a process consisting of the following steps. The proper wave parameters for the model wave climate are calculated, and a control signal representing the wave paddle's displacement from its mean position as a function of time is written digitally to tape. For the plunger wave machine, this consists of a single time series since the entire wave paddle moves in unison. The waves are generated and analyzed, and the control signal time series is then modified to increase or decrease the wave height. No correction is generally needed for the wave period.

Wave gauges

Gauges were placed in the model to measure wave conditions generated by the wavemaker so that needed adjustments to the wave signal could be calculated. Three parallel-wire capacitance gauges were used to measure model wave heights and were located along the 9-m (30-ft) depth contour (Figure 7). To ensure accurate measurements of the water-surface elevation, wave gauges were calibrated each day.

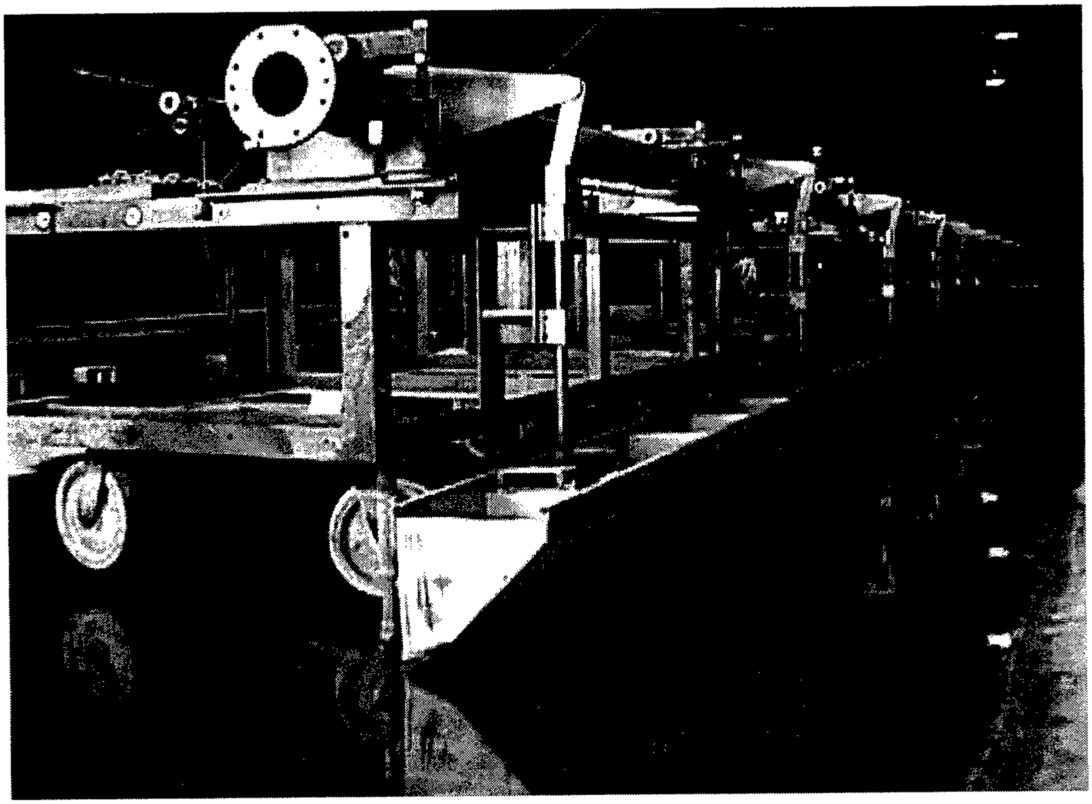

Figure 6. Plunger-type wave generator used in physical model study

Computer support

Four computer systems were used throughout the study. The tasks that these computers accomplished include generation of the control signals for simulating the wave fields, collecting wave data, tracking the design vessel, and analyzing the data.

Water-level controller and point gauge

Water depth was maintained within ±0.01 cm (0.002 ft) of the desired level by an automatic water-level float and an on/off solenoid control valve. When the float fell below a predetermined position, water was allowed to flow into the model until the appropriate level was again reached.

Design Vessels

Two design vessels, approximately the same size but with different hull shapes, were utilized during these present navigation simulation experiments. The primary design vessel used during this study had a bulk-cargo carrier hull

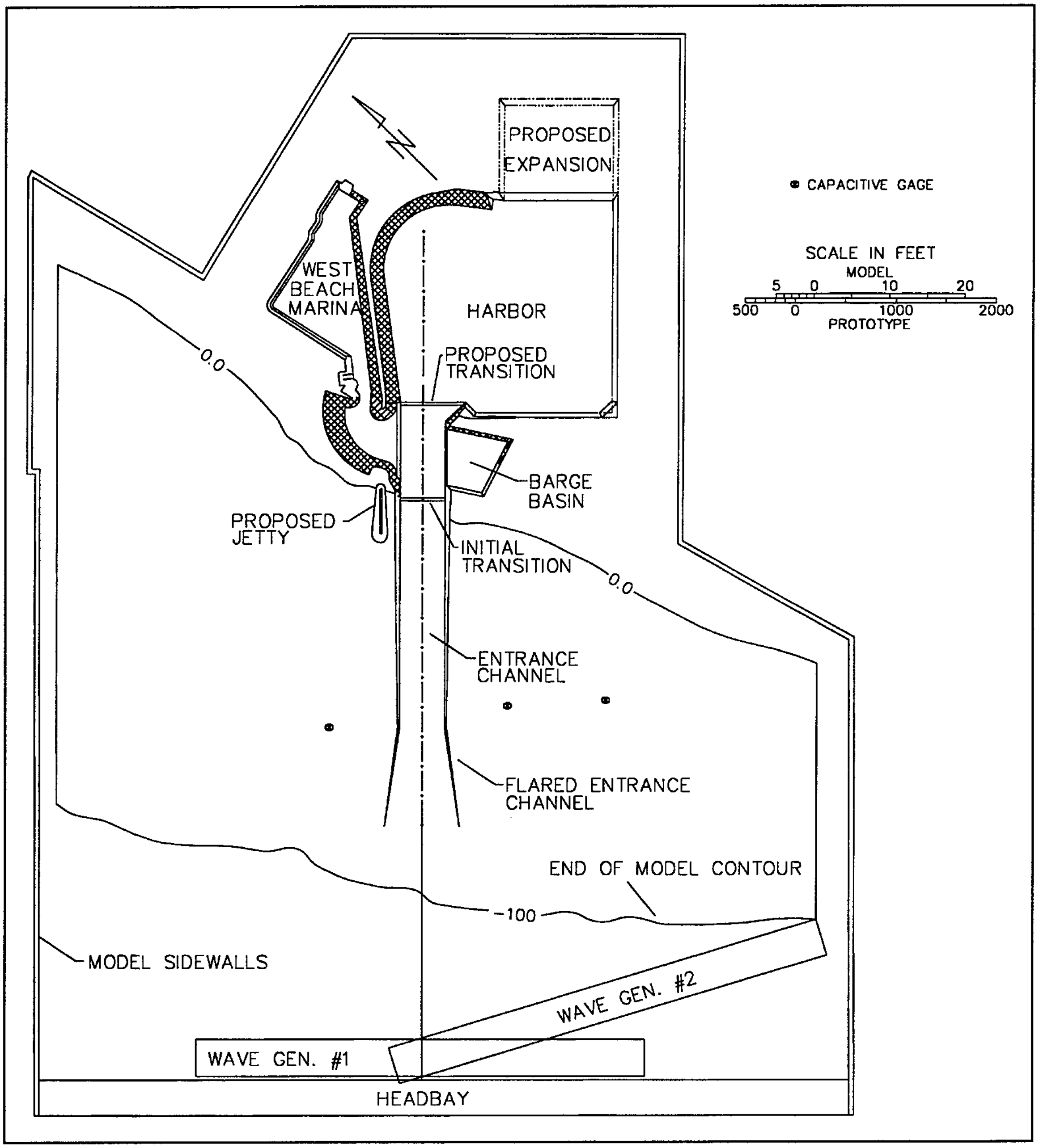

Figure 7. Physical model layout, including wave generator and gauge locations

shape (modified Bunga Saga Empat). Barbers Point Harbor was originally designed to assist the island sugar industry by exporting bulk products to the U.S. mainland. Coal is also shipped through Barbers Point. Through economic analysis, POD determined that the largest savings in shipping costs could be realized by coal bulk-cargo transportation. The secondary design vessel used in this present study was a more streamlined APL C9-class containership.

Modified Bunga Saga Empat bulk-cargo carrier

A model of a bulk-cargo carrier (a modified Bunga Saga Empat) was constructed to use as one of two design vessels (Figure 8). The dimensions of the actual prototype vessel are as follows:

Length = 229 m (750 ft)
Beam = 32 m (106 ft)
Loaded draft = 12.2-13.7 m (40-45 ft)

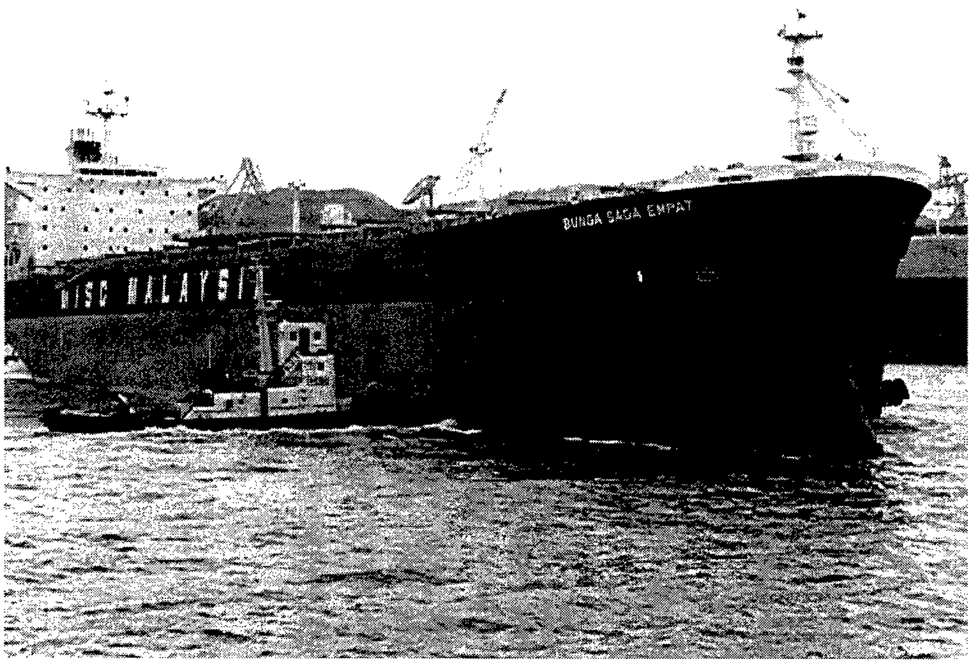

Figure 8. Bulk-cargo carrier Bunga Saga Empat from which the primary model was developed

However, POD decided to extend the length of the Bunga Saga Empat by 31 m (100 ft) so that this design vessel had an overall prototype length of 259 m (850 ft).

The model of the Bunga Saga Empat was constructed at the same 1:75 scale as the Barbers Point Harbor physical model, from a single blueprint and one photograph of the prototype (Figure 8). The dimensions of the design vessel are given in Table 2, and a photograph of the model vessel is given in Figure 9.

A 12-volt battery powered the variable speed motor and propeller assembly. Motor speed, direction, and rudder control were all remotely operated using a custom-built controller. Vessel speed was accurately controlled using a digital tachometer. Prior to simulating wave conditions, speed runs were made in deep water. The tachometer setting that reproduced the selected speed was recorded and used on subsequent runs when waves were present. Before each model run, the motor speed was adjusted to the correct settings while the model

Table 2
Dimensions of Primary Design Vessel, Modified Bunga Saga Empat

	Prototype Dimensions, m (ft)	Model Dimensions, m (ft)
Length	259 (850)	3.45 (11.3)
Beam	32 (106)	0.43 (1.4)
Loaded draft	13.7 (45)	0.18 (0.6)

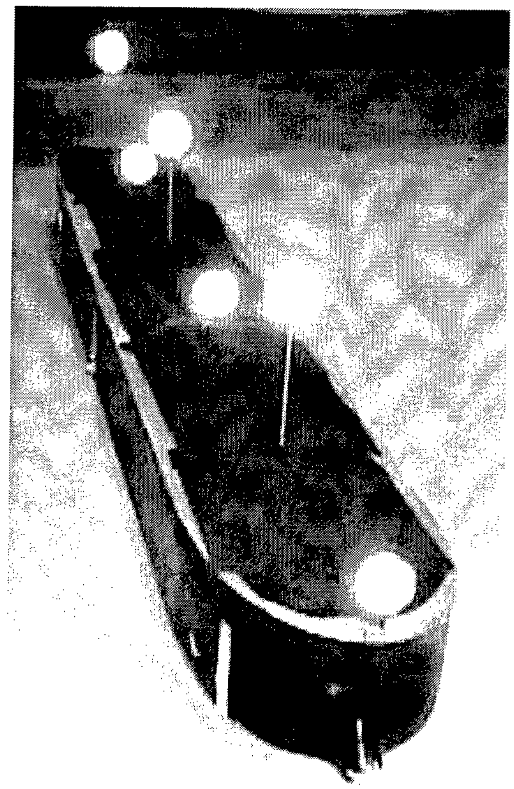

Figure 9. Physical model of the primary design vessel, the modified Bunga Saga Empat bulk-cargo carrier

ship was held stationary. The vessel was then released at the proper time. Differences in vessel speed are attributed to wave conditions and proximity to the bottom.

APL C9-class containership

A model of an APL C9-class containership had been constructed for previous physical model experiments conducted at WES in 1990, and that vessel was retrofitted as the second design vessel for use in this present study. Unlike the

modified Bunga Saga Empat model, the APL C9-class containership model has a much sleeker hull shape (Figure 10). For navigation experiments, the containers stacked on the deck were replaced with equivalent flush-mounted weights and reflective video-tracking balls.

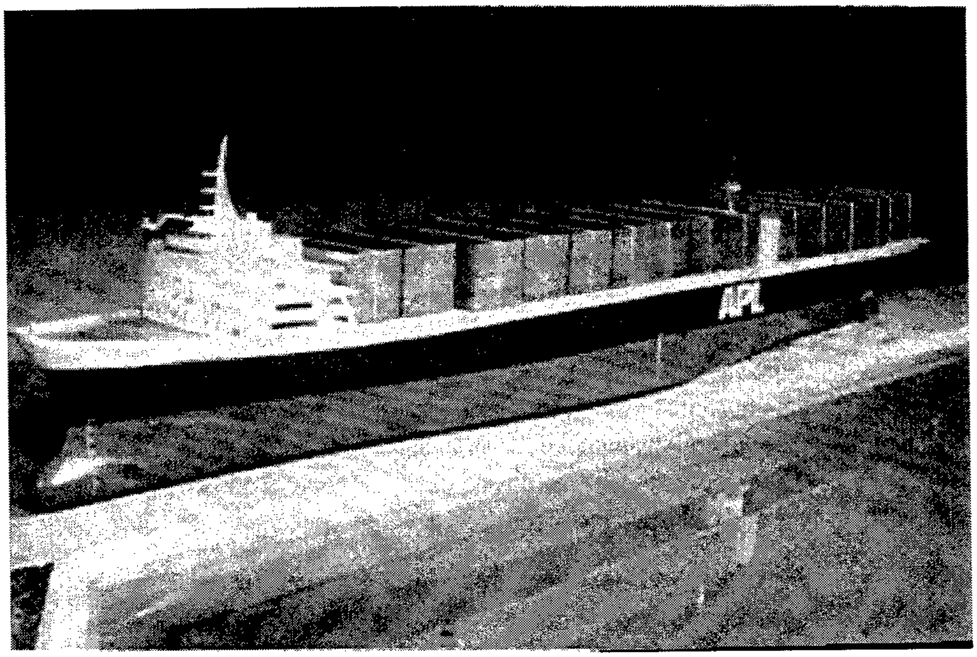

Figure 10. Physical model of the secondary design vessel, the APL C9-class containership

Model Vessel Calibration

Modified Bunga Saga Empat bulk-cargo carrier

The primary design vessel was the modified Bunga Saga Empat. To satisfy true Froude scaling laws, a model must be geometrically (both in shape and size), kinematically, and dynamically similar to the prototype. Since detailed specifications of the vessel could not be obtained from Hyundai Heavy Industries (shipbuilder of the Bunga Saga Empat), a numerical model was utilized to calculate the dynamic and kinematic vessel characteristics.

The first step in calibrating the vessel was to calculate the weights required for each draft. To calculate the weights, the shape of the hull had to be reproduced in the numerical model to determine the weight of the displaced water for the different draft conditions. The total weight needed to reach each draft is equal to the weight of water displaced. The vessel should have neither trim (difference in elevation between the front and the back of the vessel) nor heel (difference in elevation between the sides of the vessel).

Ships have a natural period of response to waves that must be reproduced in the physical model. An unrestrained vessel is free to move in six degrees of freedom (defined in Figure 11), including three translational motions and three rotational motions. For underkeel clearance calculations, vertical motions consisting of heave, pitch, and roll are exceedingly important. Translational heave motion is a function of the vessel shape and the vertical distribution of the weights. Heave occurs when the vessel moves up and down as one unit. Roll and pitch motions are a function of the horizontal and vertical placement of the weights. Roll occurs when the vessel rotates about a line running through the center of mass of the vessel along the long horizontal axis of the vessel. The center of mass is a point at which the entire weight of the vessel could be placed and the vessel would behave the same. Pitch motion is rotation through the center of mass along a line through the short horizontal axis of the vessel.

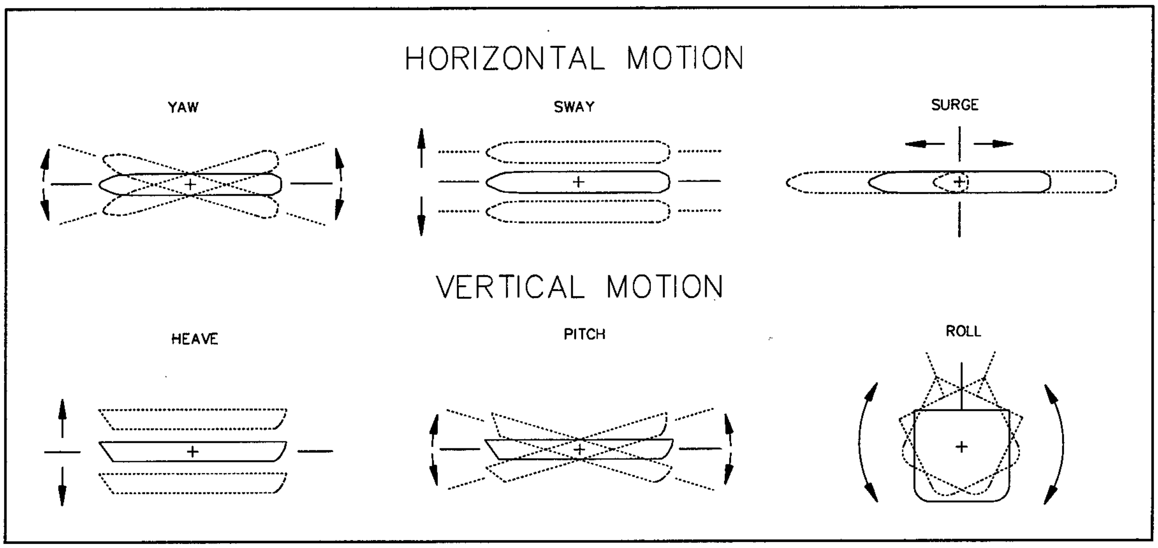

Figure 11. Six degrees of freedom for vessel subject to wave motion

The natural response of an unrestrained vessel can be displayed graphically. A numerical model generates the response amplitude operator (RAO) curves for the particular vessel draft and water depth (Figure 12). The RAO curves indicate the motion (either translational or rotational) of a stationary vessel to waves of different wave periods. (The direction of the waves varies based upon the motion, but the directions are chosen to produce maximum translation or rotation.) The x-axis indicates the prototype period of vessel response, while the y-axis has dual units. The two rotational motions (roll and pitch) have units of degrees/feet, while the translational motion (heave) has units of feet/feet. The values on the y-axis indicate the degrees of rotation for a unit wave height for the rotational motion or the distance of vertical excursion for the translational or heave motion.

To simulate the prototype weight distribution, 2.26 kg (5 lb) of lead weights were distributed throughout the model hull (Figure 13). First, the vessel draft was checked by mounting "J-shaped" point gauges to the model vessel

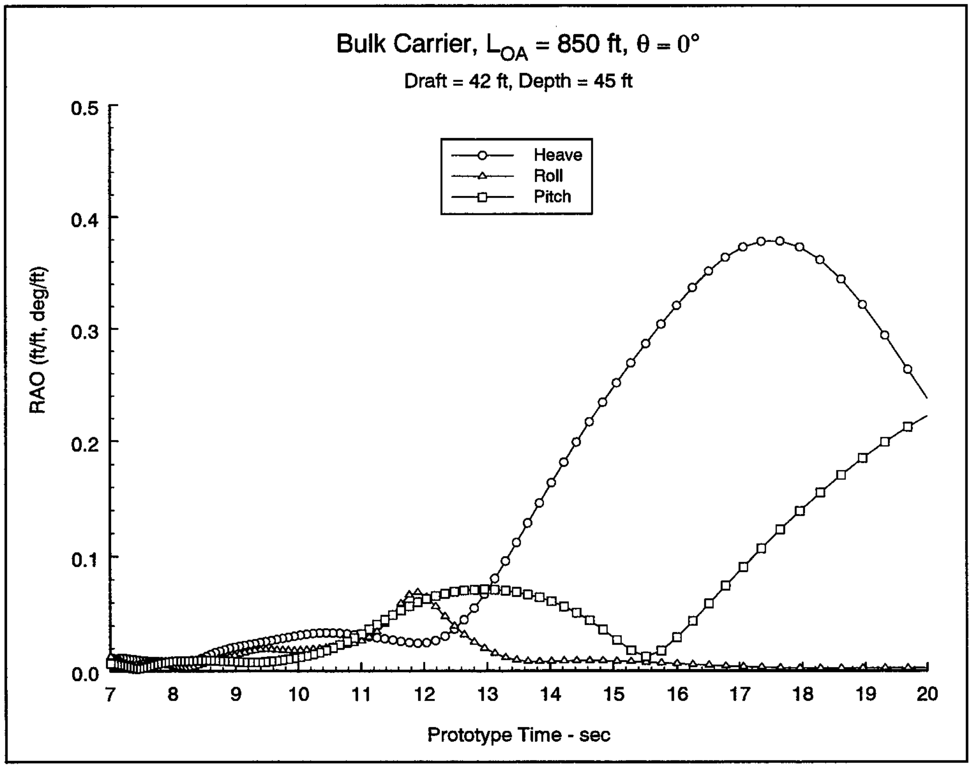

Figure 12. Response amplitude operators for 12.8-m (42-ft) vessel draft in 13.7-m (45-ft) water depth

(Figure 14). The "J-shaped" point gauges were mounted to the front and rear along the center line of the vessel and to the left and right sides along the hull at midship position (Figure 15). The weight of the point gauges was accounted for while the boat was being drafted. After the correct drafts were reached, the dynamic response of the vessel was simulated by displacing the vessel in the appropriate direction. The response period of the vessel was checked by using stop watches and by counting the number of cycles.

APL C9-class containership

The secondary design vessel, the APL C9-class containership, had been used in earlier tests and was refurbished and instrumented for the present study. Unlike the modified Bunga Saga Empat that was numerically modeled to determine the six degrees of freedom, the characteristics of the APL C9-class containership were provided by the manufacturer and were reproduced during the 1992 Barbers Point Harbor study. This vessel had previously been appropriately ballasted.

Figure 13. Distribution of lead weights throughout the hull of the model of the modified Bunga Saga Empat bulk-cargo carrier

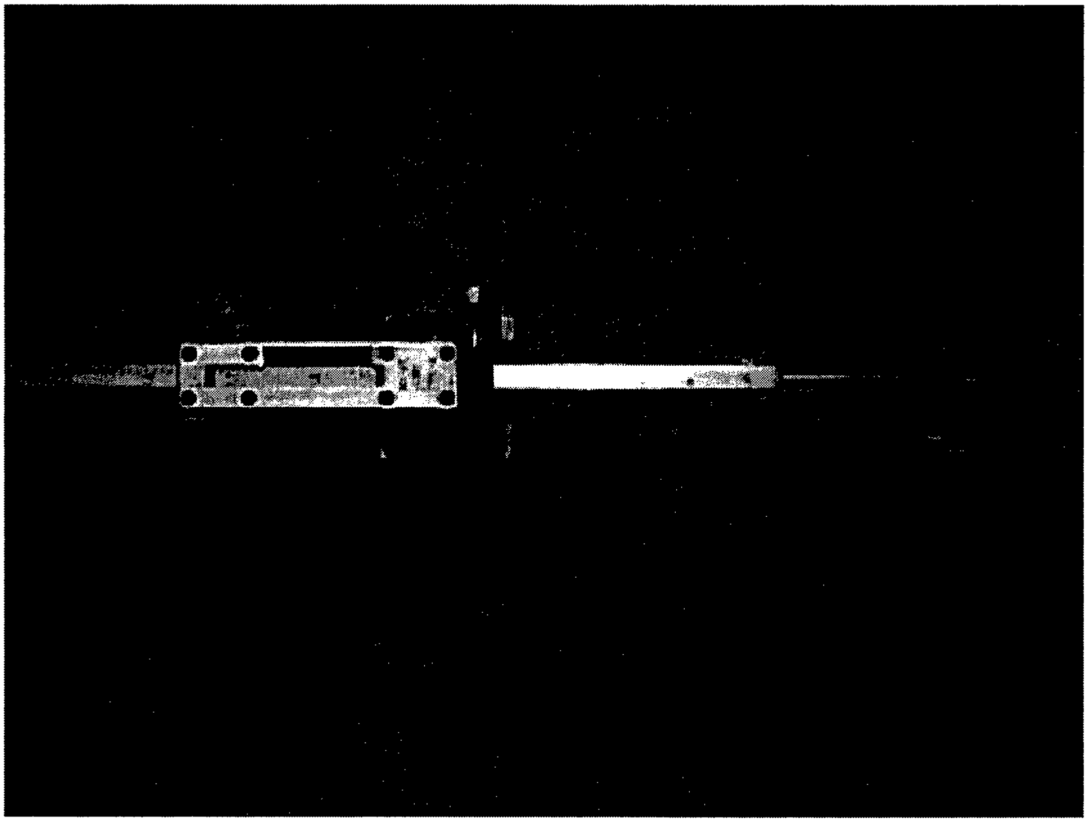

Figure 14. "J-shaped" point gauge

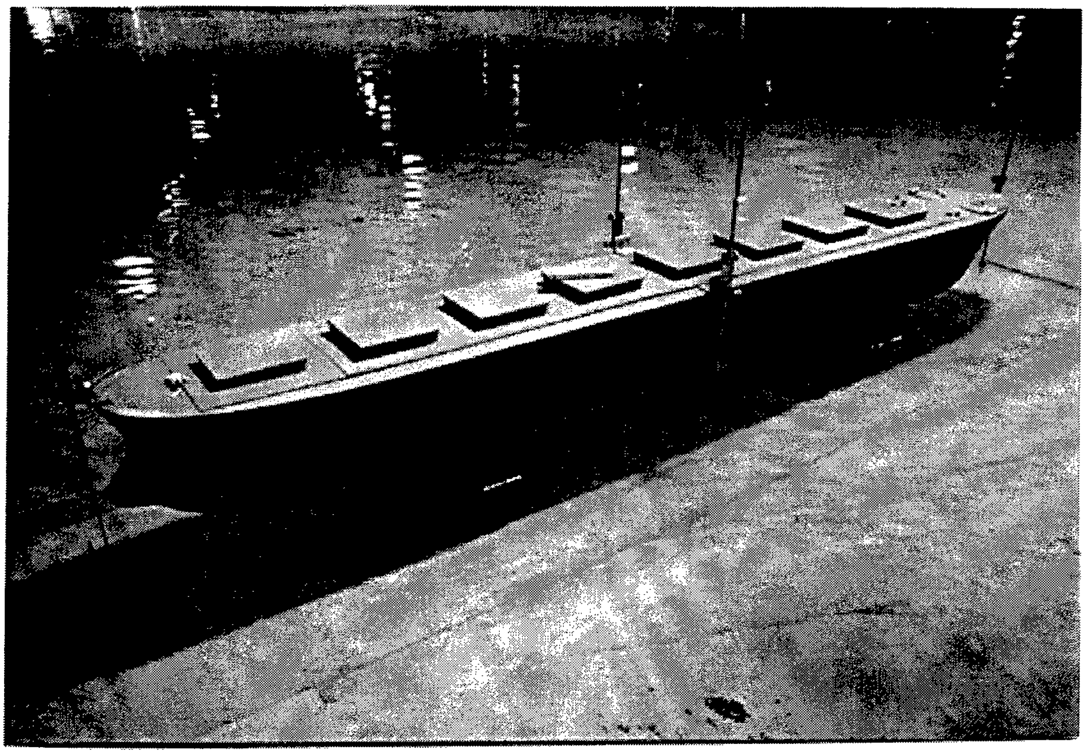

Figure 15. Location of "J-shaped" point gauges on the model of modified Bunga Saga Empat bulk-cargo carrier

3 Vessel Motion Analysis

A software and hardware system developed by Motion Analysis Corporation was used to collect and analyze the model ship motion. This is a video-based system that uses cameras and strobes to track reflecting balls in the field of view. By using six Styrofoam reflecting balls on the vessel and four Styrofoam reflecting balls located around the channel, the distance as a function of time between the vessel and the bottom could be defined.

The 0.6-m (2-ft) prototype difference between the State HDOT and the Corps POD harbor underkeel clearance criteria translates to 0.8 cm (0.32 in.) at model scale. The model arrangement had to measure at least 0.3-m (1-ft) prototype underkeel clearances, which translates to 0.4 cm (0.16 in.) at model scale.

Motion Analysis Equipment Operation and Model Vessel Arrangement

The motion analysis equipment uses Charged Coupled Device digital cameras to record the motion of reflecting targets. Six Styrofoam balls were wrapped with highly reflecting tape and mounted above the ship hull. Styrofoam was used to keep the weight down so that the reflecting targets did not modify the vessel motion. The balls were mounted above the ship hull using threaded steel rods anchored with wooden base plates. The vessel superstructure was removed during data-collection efforts to minimize masking of the targets from the cameras. However, the weight of the superstructure was accounted for with lead weights.

Three noncolinear points in space are needed to define a geometric plane. If these three points move as a rigid body, then the motion of the plane can be determined. Three balls were needed on the vessel to determine the motion of the vessel. However, if only three balls were used, when one of the balls left the field of view, motion of the vessel could not be determined. By using six balls, at least three balls stayed in the field of view for a longer period of time.

The balls were located at two elevations above the deck so that the points are not linear, which makes the calculation of the roll component possible. The

distance between the upper ball and the lower ball was determined from the expected instrumentation error. The horizontal separation between the balls needed to be at least 15 cm (6 in.) to give at most 0.3 m (1 ft) error in the prototype measurement for a worst-case situation in which the error in the location of the centroid of the balls was off by 0.25 cm (0.1 in.) in opposite directions at a particular instance in time. The balls were placed 23 cm (9 in.) apart vertically, thus providing a worst-case instrumentation error of 0.2 m (0.7 ft) prototype in the rotational motion. The ball mount had to be rigid and light; thus, there was a tradeoff between increasing the difference between the elevation of the balls to decrease the effect of instrumentation error and keeping the mounts as stiff and light as possible. Schematics of the ball locations on the modified Bunga Saga Empat bulk-cargo carrier and the APL C9-class containership are shown in Figures 16 and 17, respectively. The balls were labeled sequentially starting with ball number 1 at the front of the boat.

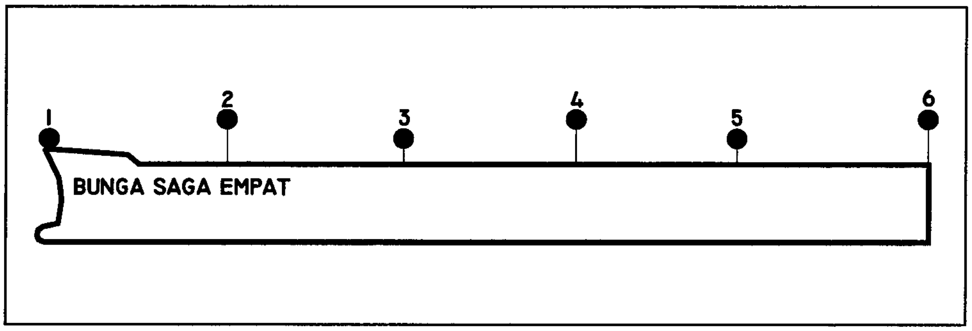

Figure 16. Location of reflecting balls on the modified Bunga Saga Empat bulk-cargo carrier

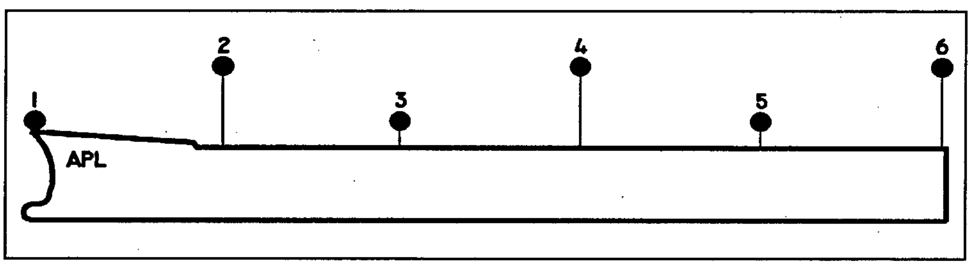

Figure 17. Location of reflecting balls on the APL C9-class containership

Motion Analysis Equipment Positioning

Before laboratory navigation runs could commence, the accuracy of the laboratory arrangement of the motion analysis system had to be defined. The initial laboratory arrangement of the motion analysis cameras used three cameras

located approximately 20 ft[1] from the entrance channel center line (Figure 18). The six-camera arrangement covered the entire length of the entrance channel. Although the manufacturer claimed accuracies of 1 mm (0.04 in.) over the entire field of view, accuracies measured by calculating the distances between rigidly mounted balls over the field of view were roughly twice the manufacturer claims (at best). To obtain the level of accuracy desired, the initial laboratory arrangement of three cameras covering a 20-ft field of view was abandoned when the accuracy of the system could not be resolved to better than approximately 0.25 m (1.6 ft) prototype overall. To obtain the level of accuracy required by the study, six cameras were used with a combined field of view of 15 ft along the entrance channel.

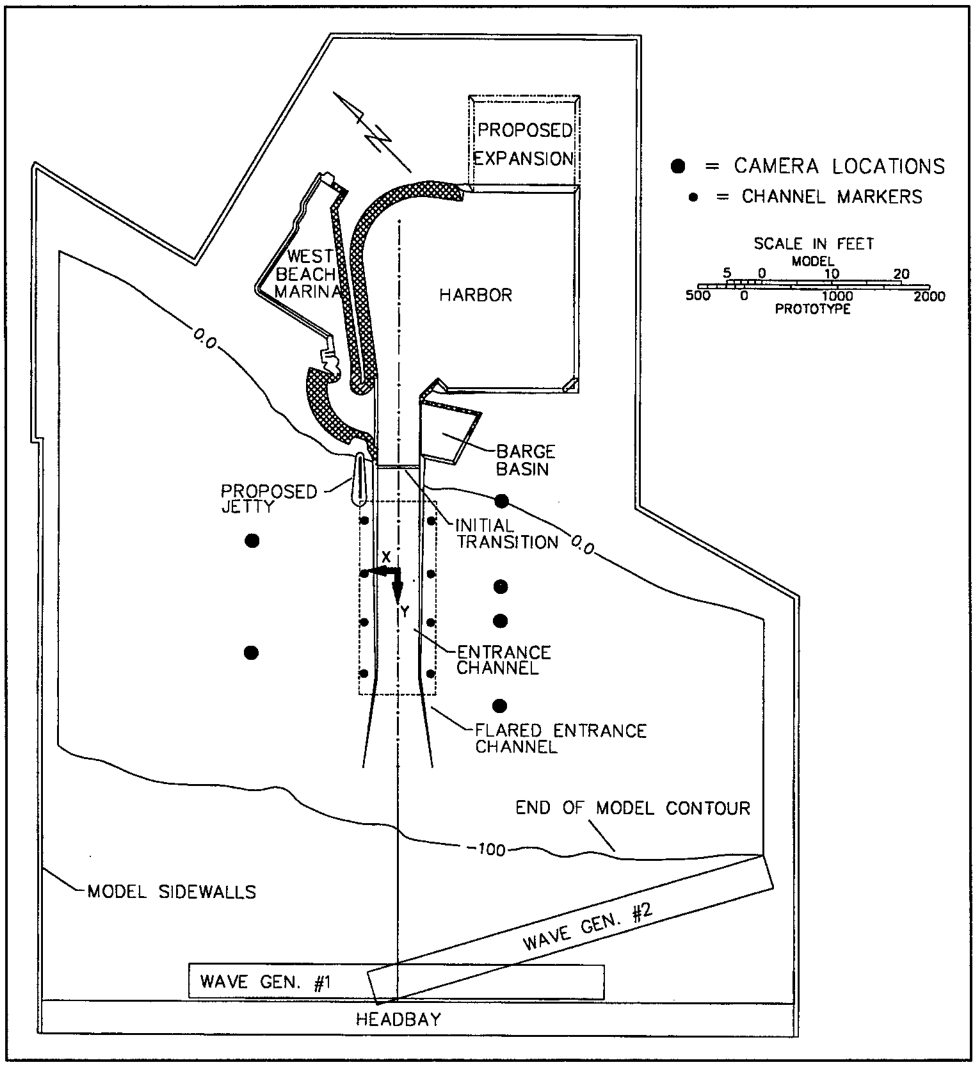

Figure 18. Initial arrangement of motion analysis cameras

[1] To convert feet to meters, multiply by 0.3048.

Early in the study, it was observed that the transition between the harbor and entrance-channel depths was an area of possible groundings. This is the area that was covered in detail with the 15-ft field of view (Figure 19). Since the channel is quite long, a second concise sampling effort was undertaken in the channel. The camera arrangement for this effort is shown in Figure 20.

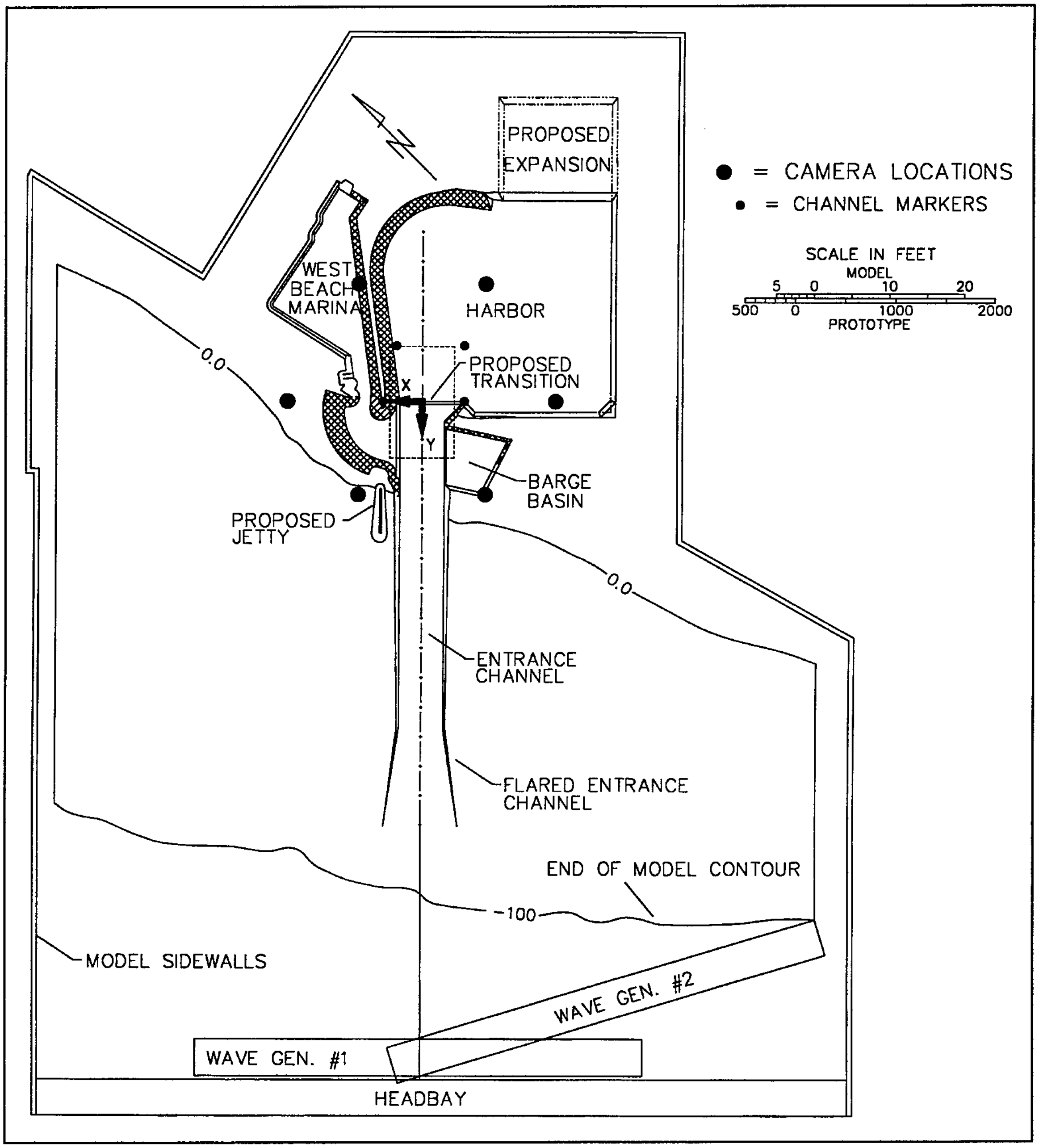

Figure 19. Camera arrangement for the transition area data collection

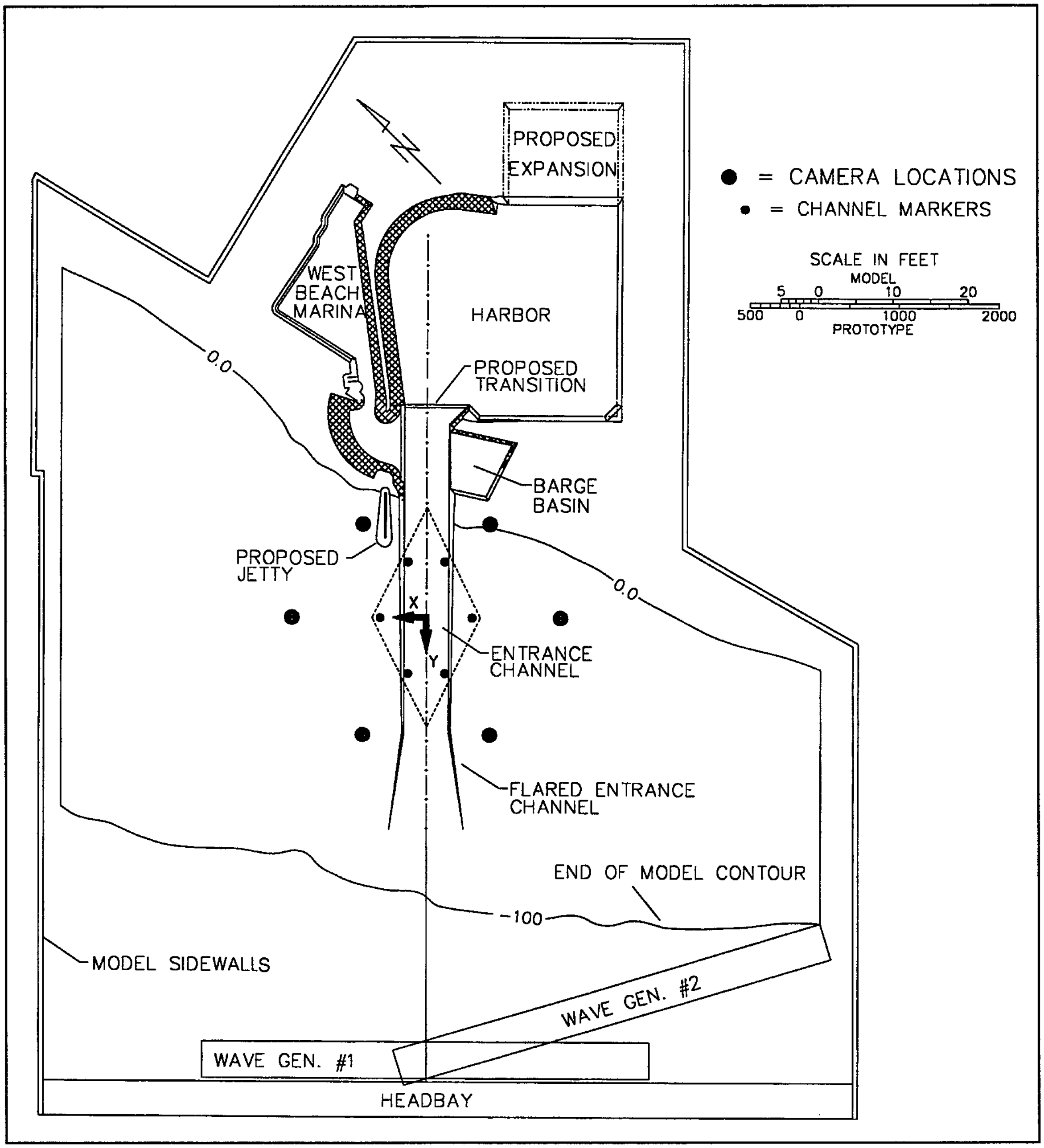

Figure 20. Camera arrangement for channel area data collection

Calibration of Field of View

The cameras were placed in approximately the shape of a circle positioned at a 6-m (20-ft) radius around the center of the field of view. This radial distance from the center of the field of view was chosen so that each camera could see its entire portion of the channel. The locations around the perimeter of the circle were chosen so that each camera could see all six reflecting balls on the vessel

and were not in line with the direction of vessel travel (i.e., no cameras were mounted at the ends of the channel). After the camera positions were established, a calibration procedure was performed to obtain a three-dimensional (3-D) mapping of the field of view. A calibration cube was first placed in the field of view and oriented so that all six cameras had a clear view of each of the reflecting sources located at the eight corners of the cube. Data were collected and digitized for 2 sec at 60 Hz for each of the six cameras. A file was then created that took into account the six different camera lens' characteristics and their associated distortions and the location of the cameras to reproduce an accurate map of the calibration cube position.

The calibration cube was 0.77 m (2.52 ft) long, 0.53 m (1.7 ft) wide, and 0.62 m (2.03 ft) tall. To increase the accuracy of the mapping of areas beyond the calibration cube, a calibration wand was moved throughout the field of view. The calibration wand was 1.5 m (5 ft) long with three reflecting balls located 0.3 m (1 ft) and 1.2 m (4 ft) apart.

To test the accuracy of the final 3-D mapping, the modified Bunga Saga Empat was propelled through the field of view. The distances between the reflecting balls were then calculated, with the first distance being subtracted from the remaining values. The subtraction of the first value was done to remove the actual distance so that values relative to zero could be evaluated. For a perfect mapping of the 3-D space with no instrument error, the values would all be zero. The results from the distance measurements between balls 1 and 2, between balls 2 and 3, and between balls 3 and 4 are shown in Figure 21. Here are shown unedited data with no quality checks. Some outliers or points far from zero can be seen that would be removed if the underkeel clearance values were to be calculated. The majority of the points are within ±0.1 in. There is a slight trend to the data that on subsequent analysis of the underkeel clearance results was removed from the data and will be discussed later.

Calculation of Underkeel Clearance

Virtual markers

The reflecting balls used to calculate the motion of the vessel were mounted above water, and thus a method to calculate the underkeel clearance of the vessel was needed. The Motion Analysis Corporation software package provides a means to identify virtual markers at any position on the vessel. Assuming a rigid body and given the location of three of the balls on the ship, any point along the vessel keel could be identified. Although outlining the entire hull of the ship with virtual markers was possible, the amount of data then collected would be unmanageable and exceedingly intensive computationally and was unneeded to accomplish this study purpose.

By identifying key locations along the hull, the maximum vertical excursion of the vessel can be ascertained. For the modified Bunga Saga Empat bulk-cargo carrier, placing virtual markers as shown in Figure 22 provided the maximum

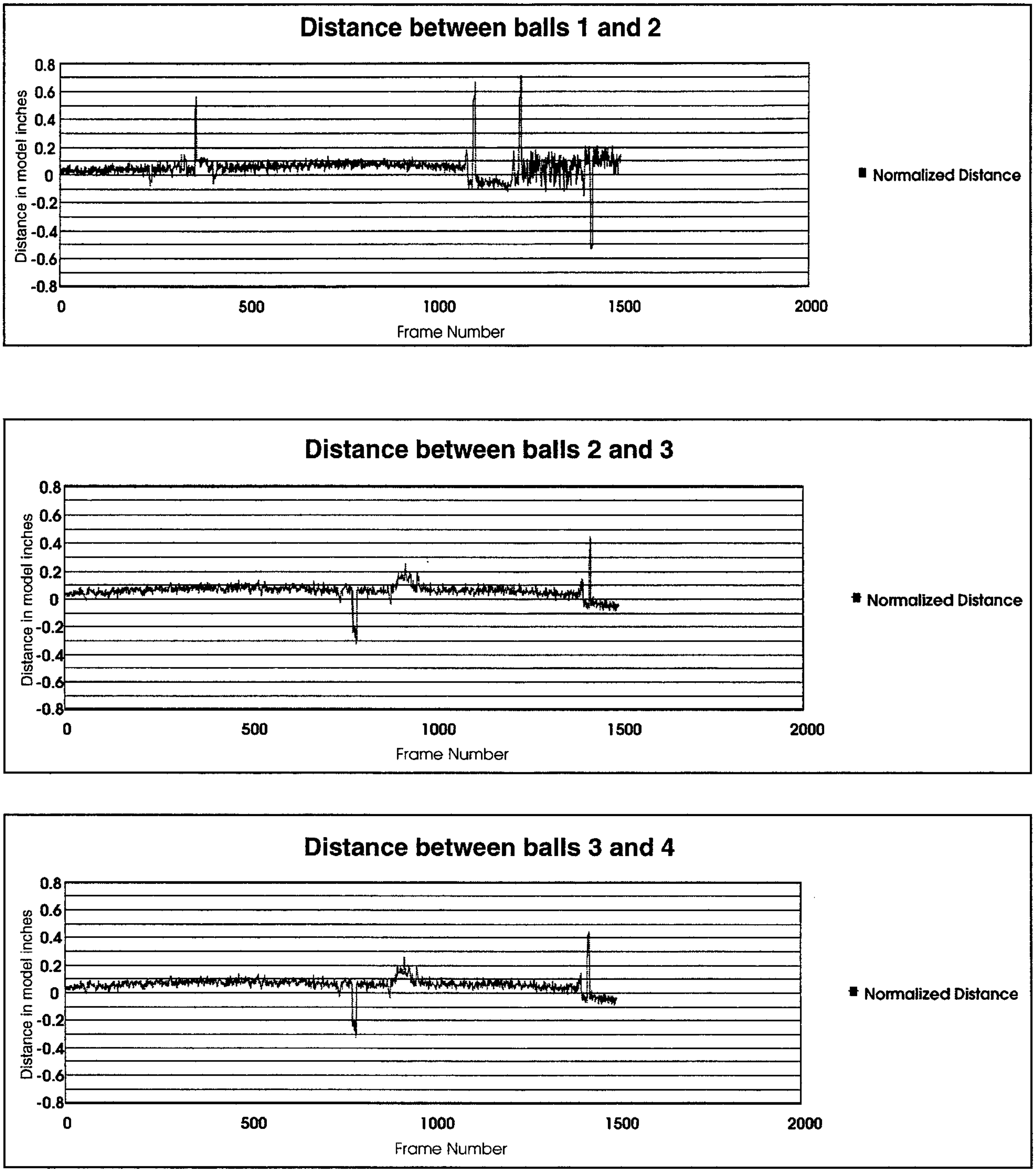

Figure 21. Examples of unedited instrument error

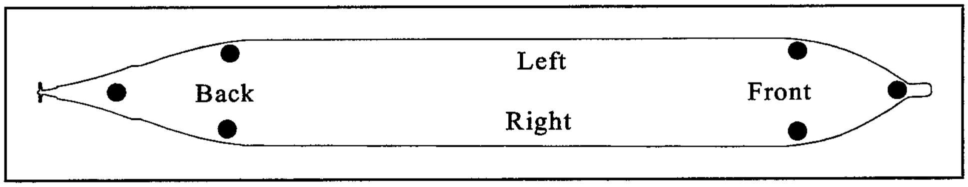

Figure 22. Location of virtual markers on modified Bunga Saga Empat bulk-cargo carrier for computing underkeel clearance

vertical excursion for either the translational or rotational motions. For pure pitch, the two markers along the center line of the vessel at the front and back provided the location of maximum motion, while the off-center points captured pitch/roll combined motion.

The shape of the APL C9-class containership warranted different virtual marker locations. For the sleek-hulled vessel, virtual markers located at four positions were needed (Figure 23). Again, two virtual markers placed one at the front and one at the back of the vessel captured pure pitch motion, while the two virtual markers located along the sides of the vessel at midpoint defined pure roll motion.

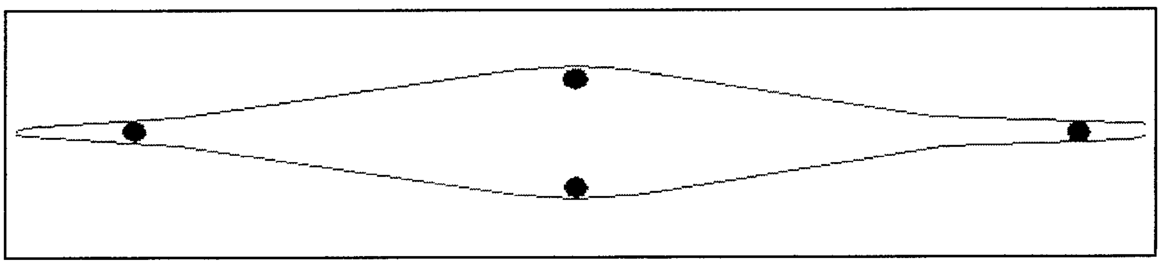

Figure 23. Location of virtual markers on APL C9-class containership for computing underkeel clearance

Establishing location of hull above the bottom

The cube and wand calibration established an arbitrary coordinate system, but defined the spatial relationship of the cameras. However, a coordinate system relative to the physical model was needed. The system software provides the ability to perform a hierarchal translation and rotation of the coordinate system. Using the stationary markers located around the channel (Figures 18, 19, and 20), the arbitrary coordinate system was transposed into a coordinate system where the x-axis points toward the channel sidewalls, y-axis lies along the center of the channel pointing seaward, and the z-axis points up. The origin lies at the transition location for the first camera arrangement (Figure 19) and in the center of the capture view for the second camera arrangement (Figure 20).

To establish the vessel position relative to the harbor bottom, the following technique was employed. Before navigation runs were performed for each water

depth/draft configuration, an initial data collection of the vessel facing into and out of the harbor was performed. The vessel was positioned so that the third ball was located over the coordinate origin, and data were recorded for 5 sec. Using the static underkeel clearance and the initial position of the vessel, the underkeel clearance during experimental runs could be calculated.

4 Selection of Experimental Conditions

The estimated cost to dredge Barbers Point Harbor and channel to -43 ft mllw and -47 ft mllw, respectively, is $30 million (POD 1996). Decreasing the depth in the harbor and entrance channel by 1 ft would save approximately $6 million. Although the 2-ft underkeel clearance difference between the State HDOT and the Corps POD criteria is small, it translates to over $12 million. To determine the underkeel clearance criteria necessary for safe transit through the channel and into the harbor, two design vessels were evaluated with 12 combinations of wave period and height for two incident wave directions. Data were collected on both the inbound and outbound travel directions.

Wave Climate

Wave height and period

Information about the wave conditions found at Barbers Point Harbor was extracted from a data collection effort begun in 1986.[1] A Datawell waverider buoy located approximately 1.6 km (1 mile) offshore (21° 20.1" N latitude, 158° 9.0" W longitude) at 200-m (650-ft) depth was installed to provide wave height and period data for the incident deepwater waves. This buoy was located in water deep enough to minimize the bathymetric effects on the measured waves. The waverider buoy uses a vertically stabilized accelerometer to sense the vertical component of the buoy's motion. Vertical acceleration and displacement data are transmitted up to 50 km (30 miles) from shore. Data were collected from July 1986 through March 1990 and are shown in Table 3.

The median wave height from the offshore waverider buoy falls in the 0.9-m (3-ft) wave-height bin. The median wave period falls in the 7-sec period band; however, waves with periods around 13 sec are also very common.

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1 Lillycrop, L., Briggs, M., Harkins, G. Boc, S., and Okihiro, M. (1993). "Barbers Point Harbor, Oahu, Hawaii, Monitoring Study," Technical Report CERC-93-18, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Waves chosen for the navigation runs should represent typical conditions found at Barbers Point. Also, wave heights should not exceed those under which a harbor pilot would be willing to bring a vessel into harbor. The vessel response is a function of the joint wave height and period. However, smaller wave heights will produce smaller motions of the vessel. POD desired to determine the maximum significant wave height under which the harbor pilots would consider bringing a design vessel into the harbor and in what water depth the wave heights they had determined as being important should be measured. However, a specific water depth and wave height could not be determined. Based upon guidance from POD, the wave conditions defined in Table 4 were reproduced in the physical model for these navigation studies. Selected experimental wave conditions were defined at the 9.1-m (30-ft) contour. To ensure wave conditions were correctly reproduced in the physical model, wave gauges were placed along the 9.1-m (30-ft) depth contour (Figure 7).

Table 3
Buoy Percentage Distribution of Deepwater Significant Wave Height and Period

	Peak Period, sec										
Significant Wave Height, H_s (ft)	**22+**	**20**	**17**	**15**	**13**	**11**	**9**	**7**	**5**	**Sum of Observations**	**%**
10+			1	2						3	0.1
9				1	4	1		3		9	0.2
8		5	6	4	6	2	2	2		27	0.7
7		4	3	20	8	9	6	9	1	60	1.6
6		4	8	33	30	29	16	13		133	3.6
5		1	22	79	92	49	35	35	6	319	8.6
4		11	62	173	237	176	145	208	37	1,049	28.2
3		10	47	182	384	307	306	527	87	1,850	49.8
2			4	16	65	55	44	60	18	262	7.1
1							4			4	0.1
Sum of Observations		35	153	510	826	628	558	857	149	3,716	
%		1.0	4.1	13.7	22.2	16.9	15.0	23.1	4.0		100.0

The waves were calibrated at the three gauge locations by first generating and storing the parameters listed in Table 4. The file was then used to generate waves at the same time the wave-gauge data were being collected. The data were analyzed, and corrections were made to the control signal until the target wave height was found. Table 5 shows the results for the control signals.

Table 4 Wave Conditions Reproduced in the Physical Model			
Prototype Wave Height, m (ft)	**Wave Condition Number**	**Prototype Wave Period, sec**	**Gamma (width of the spectra in the frequency domain)**
0.9 (3.0)	1	6.0	3.3
	2	10.0	5.0
	3	14.0	7.0
	4	18.0	10.0
1.5 (5.0)	5	6.0	3.3
	6	10.0	5.0
	7	14.0	7.0
	8	18.0	10.0
2.1 (7.0)	9	6.0	3.3
	10	10.0	5.0
	11	14.0	7.0
	12	18.0	10.0

Table 5 Wave Period and Height from Control Signal Calibration			
Prototype Period, sec	**Prototype Target Wave Height, ft**	**Measured Wave Height, ft**	**Percent Error, %**
6	3.0	3.02	0.75
10	3.0	2.99	0.50
14	3.0	3.17	5.75
18	3.0	2.96	1.50
6	5.0	4.87	2.65
10	5.0	5.04	0.80
14	5.0	4.81	3.85
18	5.0	5.07	1.40
6	7.0	6.80	2.82
10	7.0	7.38	5.43
14	7.0	7.10	1.46
18	7.0	7.42	5.96

Wave direction

Two wave directions were chosen to reproduce maximum vessel excursions. Vessel pitch and heave motion (see Figure 11) are most strongly excited when waves encounter the vessel from either front or back. Waves approaching directly along the channel would reproduce this condition. When waves approach broadside or at 90 deg from the long axis of the vessel, roll motion is most strongly excited. This would imply that waves are traveling perpendicular to the beach. Refraction makes this wave approach unlikely. However, a combined roll/pitch motion is strongly excited when waves travel approximately 20 deg from the long axis of the vessel. According to harbor pilots, waves from the southwest generate considerable vessel roll. The wavemaker was positioned so that waves are generated 20 deg south of the entrance channel orientation. The plunger wavemaker is a unidirectional machine; thus, to generate both wave directions, the wavemaker had to be physically moved. The two wavemaker positions are shown in Figures 18, 19, and 20.

Modifications to Existing Transition

Transition location

Presently the Barbers Point entrance channel is dredged to -12.8 m (-42 ft) mllw and the harbor to -11.6 m (-38 ft) mllw. The transition between these two depths is located at the intersection of the shoreline with the entrance channel. During early stages of this study, it became apparent that the transition would be a point of possible groundings. The waves are fairly energetic in the channel at the shoreline. It was decided to move the transition from the shoreline location to where the channel opens up to the harbor (Figure 24). This decision was based upon two reasons: decreased wave energy at the second transition and vessel shear (described next).

When a vessel transits over a bottom that goes from deeper to shallower water, the vessel will shear if the water is shallow enough. This shear is caused by increased boundary layer friction between the vessel moving through the water and the seafloor bottom. The portion of the boat in deeper water (stern) feels less friction and wants to travel more quickly than that part of the vessel in shallower water (bow). The vessel's stern will try to "fishtail" or "jackknife." By moving the transition toward the opening of the harbor, the pilot has more room to correct the vessel position.

The transition was moved to the new location, and all data were collected with the transition at this new location. The existing difference in the depth between the entrance channel and the harbor of 1.2 m (4 ft) was used for the first series of experiments.

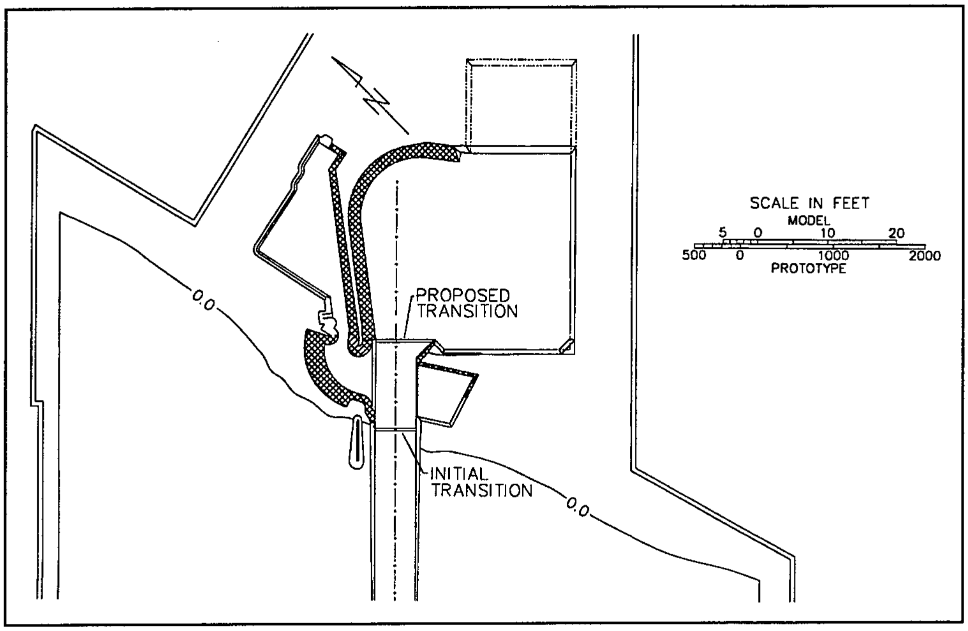


Figure 24. Location of initial and proposed transition between entrance channel and harbor

Difference in entrance channel and harbor depths

Although there is only 0.6-m (2-ft) (State HDOT criteria) or 1.2-m (4-ft) (Corps POD criteria) underkeel clearance in the harbor, there is 1.8-m (6-ft) (State HDOT criteria) or 2.4-m (8-ft) (Corps POD criteria) underkeel clearance in the entrance channel. The entrance channel is approximately 1,070 m (3,500 ft) long and 140 m (450 ft) wide. There is a potential for significant savings if depth in the entrance channel can be minimized. During the first series of experiments, it was determined that the entrance channel could be made shallower. Thus, navigation experiments were also conducted with a shallower entrance-channel depth and a smaller depth difference at the transition. A 0.6-m (2-ft) channel transition was also modeled. By adjusting the water depths, underkeel clearance values for the entrance channel and harbor, respectively, of 1.8 m (6 ft) and 1.2 m (4 ft), 1.5 m (5 ft) and 0.9 m (3 ft), and 1.2 m (4 ft) and 0.6 m (2 ft) were evaluated.

Design Vessel Draft and Water-Level Combinations

As previously discussed, there is a difference between the HDOT and the Corps POD underkeel clearance criteria in the harbor. HDOT uses a 0.6-m (2-ft) clearance, while POD uses a 1.2-m (4-ft) underkeel clearance value. It was decided that the design vessels would be drafted to reproduce both the HDOT and the POD underkeel clearance criteria for the selected water depths.

A total of 1,280 inbound and outbound runs were conducted with the two design vessels. Table 6 summarizes the vessel draft/water depth combinations evaluated by this physical model study.

Table 6
Vessel Draft and Water Depth Combinations Evaluated in the Physical Model

Vessel		Water Depth, ft		Underkeel Clearance, ft		Number of Runs		
						Incident Wave Directions		
Description	Draft, ft	Channel	Harbor	Channel	Harbor	0	20	Total
APL C9-class containership	35	41	37	6	2	48	48	96
	35	43	39	8	4	48	48	96
Modified Bunga Saga Empat bulk-cargo carrier	38	44	40	6	2	48	48	96
	36	44	40	8	4	48	48	96
	36	42	38	6	2	48	48	96
	34	42	38	8	4	48	48	96
	39	47	43	8	4	48	48	96
	41	47	43	6	2	48	48	96
	41	49	45	8	4	48	48	96
	43	49	45	6	2	48	48	96
	41	47	45	6	4	16	16	32
	41	46	44	5	3	16	16	32
	41	45	43	4	2	16	16	32
	43	49	47	6	4	16	16	32
	43	48	46	5	3	16	16	32
	43	47	45	4	2	16	16	32
	39	45	43	6	4	16	16	32
	39	44	42	5	3	16	16	32
	39	43	41	4	2	16	16	32
	42	47	45	5	3	16	16	32
Total								1,280

Vessel Speed

Harbor pilots provided typical vessel transit speeds into and from the harbor. They noted that vessel speeds on the inbound transit varied from 7 knots at the channel entrance to 2 knots in the harbor. On the outbound transit, vessel speed increased from 2 knots in the harbor up to 10 knots at the channel entrance during rough conditions and strong currents. Vessel speeds of approximately

5 knots were used for experiments around the transition as well as in the entrance channel.

5 Physical Model Results and Conclusions

Over nine gigabytes of data were collected during the approximately 1,000 transits into and out of the harbor for the six virtual markers on the modified Bunga Saga Empat bulk-cargo carrier and the four virtual markers on the APL C9-class containership. All the data are not presented here, but summarized data are provided in tabular and graphical form.

Early in the study, it became apparent that the area around the transition could be a region of maximum vertical excursion of the vessel. The majority of the data-collection efforts were focused on this area. Accurately locating the channel depth was critically important since the channel is 945 m (3,100 ft) long. A concentrated effort with large waves was also conducted in the entrance channel.

Data Analysis Techniques

During experimental runs, data were collected at 60 Hz. At the end of the data-collection effort, video images of the reflecting balls were analyzed, and the x-, y-, z- coordinates of the six balls located on the model vessel and the balls located on the floor around the channel were identified manually. After each of the reflecting balls were identified, the computer calculated the x-, y-, z-coordinate time-history of each reflecting ball using the arbitrarily defined coordinate system. Then, the x-, y-, z- coordinates were transposed into the model coordinate system using the reflecting balls located around the channel. Assuming the model vessel was rigid, the locations of the virtual markers were calculated at each time-step. The vessel motion then was compared with a static snapshot of the model vessel in the center of the sampling area. After these calculations were made, the underkeel clearance of the moving vessel could be determined since the static underkeel clearance was measured with a caliper.

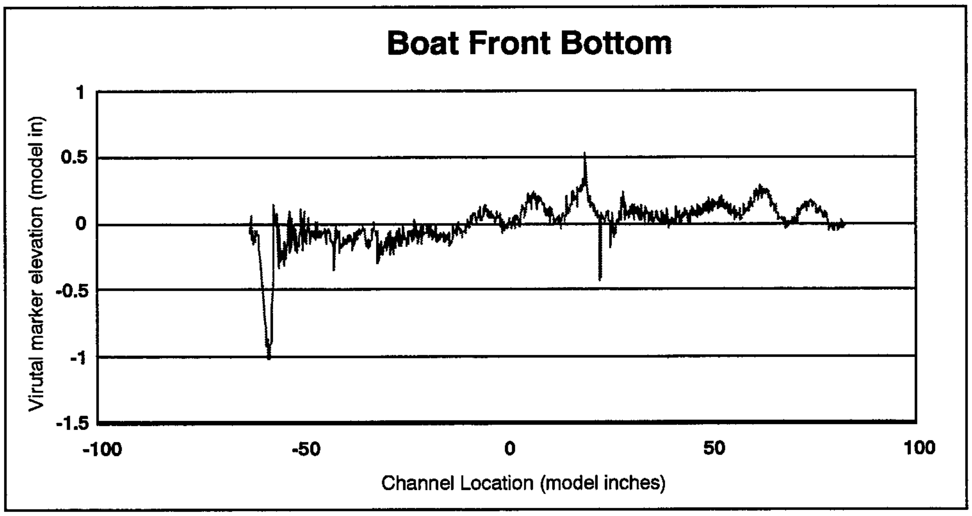
Once the locations of the virtual markers were known, the underkeel clearance was calculated, and the data were sorted into 0.3-m (1-ft) bins representing the keel distance above the bottom for each of the virtual markers

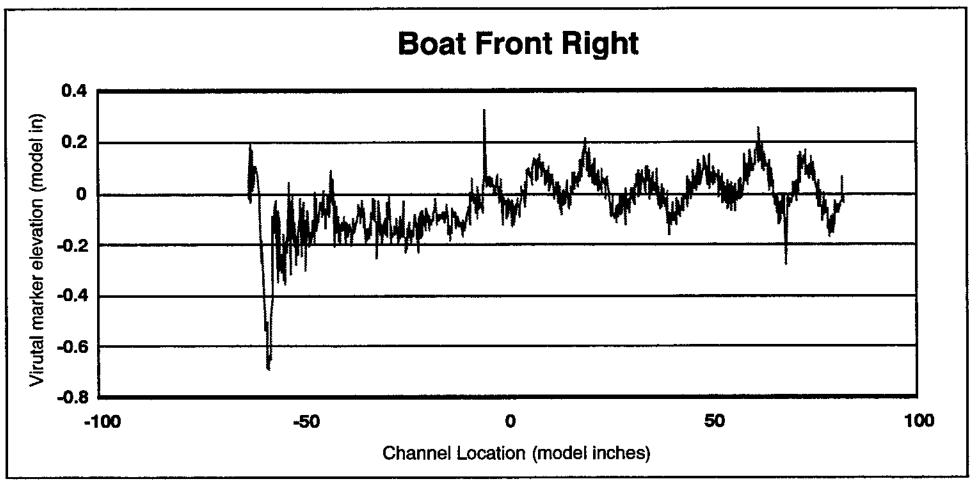
for all the navigation runs. Grouping the data into depth bins instead of presenting time-histories allowed the data to be further summarized and presented in tabular form. Instead of having six different time-histories of the location of the model vessel keel, the data for all the virtual markers were grouped together. This decreased the number of separate channels of data from six to one for the modified Bunga Saga Empat and from four to one for the APL C9-class vessel for each experimental condition. Also, the data for the inbound and outbound runs were combined into one data set for each wave condition. For simplicity, the percent occurrence in each bin is presented instead of reporting the number of occurrences of each virtual marker in each depth bin. The data have been scaled into prototype distances, with the results for the modified Bunga Saga Empat presented in Appendixes A and B for Corps POD and State HDOT criteria, respectively. The data are presented by the vessel draft/entrance channel depth/harbor depth combinations. Appendixes C and D show the results for the APL C9-class vessel for Corps POD and State HDOT criteria, respectively.

Figure 25 shows the time-history of the virtual marker trajectories for one wave case for the three virtual markers at the front of the modified Bunga Saga Empat model vessel (location of virtual markers shown in Figures 22 and 23). The left virtual marker is defined as the port side, and the right virtual marker is the starboard side of the model vessel. Figure 25 shows the results from the second camera arrangement with the sampling area entirely in the channel. The data are unedited, and some spikes in the data are visible. These would be eliminated during data quality check. The x-axis in Figure 25 shows the location along the channel, and the y-axis indicates the distance from the bottom.

Results for the Modified Bunga Saga Empat Bulk-Cargo Carrier

Tabulated results are organized by the underkeel clearance criteria used during the experiment and by the transition difference. Table 7 shows percent occurrence of keel motion for the Corps POD underkeel clearance criteria, while Appendix A shows the actual number of occurrences of keel motions for the first camera arrangement, the proposed transition location, and a 1.2-m (4-ft) transition difference. Table 8 and Appendix B show corresponding results for the State HDOT underkeel clearance criteria. The depth bins are organized in 0.3-m (1-ft) increments where ">8" indicates that the vessel keel is 2.4 m (8 ft) above the bottom. The bins below ">8" indicate that the keel is identified by the virtual marker trajectories passed in this zone. For example, for the 36/44/0 case (vessel draft of 36 ft, water depth in the channel of 44 ft, and waves arriving directly along the entrance channel) for the ">2" ft depth bin, the keel was between 0.9 m (3 ft) and 0.6 m (2 ft) from the bottom 0.367 percent of the time in the harbor. The results for the harbor are shown above the results for the channel. The last column indicates the average number of occurrences of the keel in each depth bin over the numerous vessel draft/water depth and wave





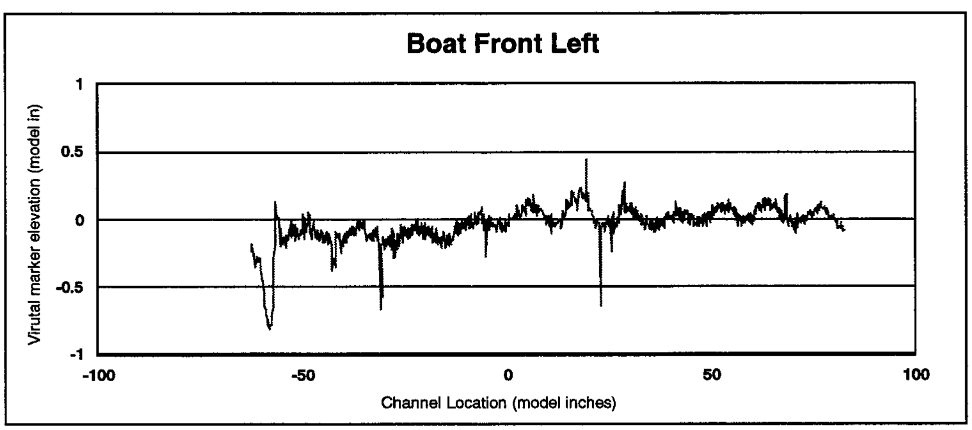


Figure 25. Unedited track of three virtual markers for the modified Bunga Saga Empat bulk-cargo carrier in the channel, 1.5-m (5-ft), 14-sec significant wave

Table 7
Percent Occurrence of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for Corps POD Underkeel Clearance Criteria for Varying Vessel Draft/Water Depth in Channel/Wave Direction Occurrences, 4-ft Transition at Proposed Location

Vessel draft/water depth in channel/wave direction	36/44/0	36/44/20	34/42/0	34/42/20	39/47/0	39/47/20	41/49/0	41/49/20	
Speed, knots	4.2	4.4	4.4	4.6	4.2	4.2	4.2	4.3	
Percent Occurrence in Each Depth Bin over the Harbor									
Depth bins, ft									Average
>8.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>7.0	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000
>6.0	0.000	0.000	0.055	0.000	0.000	0.000	0.000	0.000	0.008
>5.0	0.041	0.276	0.278	0.022	0.583	0.551	0.518	0.801	0.433
>4.0	13.397	53.011	49.515	6.546	51.926	49.923	51.394	50.280	44.656
>3.0	86.195	45.424	50.039	91.678	46.762	48.525	47.345	47.659	53.919
>2.0	0.367	1.289	0.108	1.749	0.728	1.000	0.743	1.260	0.983
>1.0	0.000	0.000	0.000	0.004	0.000	0.001	0.000	0.000	0.001
>0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bottom	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Percent Occurrence in Each Depth Bin over the Entrance Channel									
Depth bins, ft									Average
>8.0	99.350	53.615	56.372	97.144	56.486	54.323	54.800	56.178	61.274
>7.0	0.650	46.063	43.049	2.824	42.791	44.765	44.738	42.721	38.136
>6.0	0.000	0.309	0.578	0.030	0.719	0.900	0.463	1.101	0.586
>5.0	0.000	0.013	0.001	0.000	0.004	0.013	0.000	0.000	0.004
>4.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>3.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>2.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>1.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bottom	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000

Table 8
Percent Occurrence of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for State HDOT Underkeel Clearance Criteria for Varying Vessel Draft/Water Depth in Channel/Wave Direction Occurrences, 4-ft Transition at Proposed Location

Vessel draft/water depth in channel/wave direction	33/44/0	38/44/20	36/42/0	36/42/20	41/47/0	41/47/20	43/49/0	43/49/20	
Speed, knots	4	4.2	4.2	3.7	4	3.8	4.1	4.4	
Percent Occurrence in Each Depth Bin over the Harbor									
Depth bins, ft									Average
>8.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>7.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>6.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>5.0	0.000	0.000	0.046	0.000	0.000	0.001	0.000	0.001	0.006
>4.0	0.000	0.000	22.327	0.001	0.005	0.001	0.000	0.023	2.795
>3.0	0.025	0.104	23.514	0.192	0.550	0.409	0.452	4.655	3.738
>2.0	8.978	50.639	27.385	49.270	51.993	50.195	53.007	79.782	46.406
>1.0	90.458	49.175	26.614	50.435	46.854	48.184	46.074	15.382	46.647
>0.0	0.539	0.082	0.114	0.102	0.599	1.209	0.467	0.156	0.409
Bottom	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Percent Occurrence in Each Depth Bin over the Entrance Channel									
Depth bins, ft									Average
>8.0	0.000	0.002	38.311	0.000	0.004	0.018	0.005	4.086	5.303
>7.0	0.018	0.074	29.826	0.122	0.563	0.460	0.269	82.513	14.231
>6.0	9.138	54.371	19.897	58.192	50.822	49.484	52.362	13.189	38.432
>5.0	90.009	44.977	11.966	41.071	47.675	49.349	46.815	0.212	41.509
>4.0	0.836	0.567	0.000	0.611	0.919	0.670	0.546	0.000	0.519
>3.0	0.000	0.009	0.000	0.005	0.017	0.019	0.003	0.000	0.007
>2.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>1.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bottom	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

direction combinations. The average column indicates that the Corps POD criteria provide sufficient underkeel clearance in the channel and harbor. For example, the vessel is between 0.6 m (2 ft) and 0.3 m (1 ft) from the bottom 0.001 percent of the time. The average vessel speed in knots is also provided near the top of the table for each condition studied.

Results indicate that the Corps POD criteria are very conservative with few occurrences of the vessel below the 1-ft harbor underkeel clearance distance. Underkeel clearance values less than 0.3 m (1 ft) were considered unacceptable, and values of 0 indicated bottom contact. In the harbor, the 0.6-m (2-ft) clearance distance is not adequate, and the 1.2-m (4-ft) clearance distance is overly conservative. Both the 1.8-m (6-ft) and 2.4-m (8-ft) clearance distances in the channel appear to be conservative.

Additional experiments were conducted with a modified transition depth of 0.6 m (2 ft) instead of 1.2 m (4 ft). Underkeel clearances of 1.2 m (4 ft) and 1.8 m (6 ft), 0.9 m (3 ft) and 1.5 m (5 ft), and 0.6 m (2 ft) and 1.2 m (4 ft) in the harbor and channel, respectively, were evaluated. The percent occurrences of keel motion for these series of experiments have been compiled and are shown in Table 9 for the 1.2-m (4-ft) and 1.8-m (6-ft) underkeel clearances in the harbor and channel, respectively. Table 10 shows the percent occurrences of keel motion for the 0.9-m (3-ft) and 1.5-m (5-ft) underkeel clearances in the harbor and channel, respectively. Table 11 shows the percent occurrence of keel motion for the 0.6-m (2-ft) and 1.2-m (4- ft) underkeel clearances in the harbor and channel, respectively. Appendix E shows the actual number of keel motions for the appropriate corresponding conditions. (The 43-ft vessel draft, 47-ft entrance channel depth, 45-ft harbor depth, waves 0-deg orientation to entrance channel, 2-ft transition at proposed location data were inadvertently omitted from this appendix.) Results indicate that the 1.2-m (4-ft) and 1.8-m (6-ft) harbor and channel underkeel clearances, respectively, are too conservative.

Data were also collected in the entrance channel with the second camera arrangement. During this data collection, wave heights were run multiple times to provide more statistical validity. The four largest waves were run eight times each, and the results were summarized for each different replication. The percent occurrence of keel motion for these conditions are shown in Table 12. The modified Bunga Saga Empat was drafted so that there was a 1.5-m (5-ft) channel underkeel clearance. The depth in the channels was 14.3 m (47 ft), and the incident wave direction was zero. Appendix F shows the actual number of occurrences of keel motions for the appropriate corresponding conditions. Results indicate that a 1.5-m (5-ft) underkeel clearance in the channel should provide adequate clearance for the design vessel.

Results for the APL C9-Class Containership

The shape of the APL C9-class vessel is more streamlined than the modified Bunga Saga Empat, and experiments were conducted with this model vessel to

Table 9
Percent Occurrence of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat with Modified Transition for Underkeel Clearance Criteria for Varying Vessel Draft/Water Depth in Channel/Wave Direction Occurrences (Underkeel clearances in the entrance channel and harbor are 1.8 m (6 ft) and 1.2 m (4 ft), respectively)

Vessel draft/water depth in channel/wave direction	41/47/0	43/49/0	39/45/0	41/47/20	43/49/20	39/45/20	
Speed, knots	4.4	4.5	4.3	4.2	4.2	4.6	
Percent Occurrence in Each Depth Bin over the Harbor							
							Average
Depth bins, ft							
>8.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>7.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>6.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>5.0	0.960	0.159	0.065	0.153	0.339	0.030	0.177
>4.0	53.086	36.198	7.066	28.180	39.075	7.938	25.473
>3.0	44.993	62.317	84.243	69.742	59.639	82.358	70.192
>2.0	0.960	1.326	8.626	1.925	0.946	9.578	4.131
>1.0	0.000	0.000	0.000	0.000	0.000	0.096	0.027
>0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bottom	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total							
Percent Occurrence in Each Depth Bin over the Entrance Channel							
							Average
Depth bins, ft							
>8.0	0.562	0.482	0.099	0.307	0.584	0.097	0.321
>7.0	42.416	34.331	6.130	28.605	37.976	7.227	23.426
>6.0	56.180	64.499	86.083	69.535	59.584	85.013	72.238
>5.0	0.843	0.688	7.668	1.433	1.844	7.644	3.974
>4.0	0.000	0.000	0.020	0.057	0.012	0.019	0.026
>3.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>2.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>1.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

determine differences in the vertical excursion of the containership vessel. Navigation experiments with the APL C9-class vessel were conducted with the proposed transition location (Figure 24), transition camera arrangement (Figure 19), and with the existing 4-ft transition difference. Table 13 summarizes results for the four conditions studied, previously shown in Table 6.

Table 10
Percent Occurrence of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat with Modified Transition for Underkeel Clearance Criteria for Varying Vessel Draft/Water Depth in Harbor/Wave Direction Occurrences (Underkeel clearances in the entrance channel and harbor are 1.5 m (5 ft) and 0.9 m (3 ft), respectively)

Vessel draft/water depth in channel/wave direction	41/46/0	43/48/0	39/44/0	41/46/20	43/48/20	39/44/20	
Speed, knots	4.2	4.3	4.3	4.5	4.1	4.4	
Percent Occurrence in Each Depth Bin over the Harbor							
Depth bins, ft							Average
>8.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>7.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>6.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>5.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>4.0	0.201	0.000	0.014	0.222	0.366	0.055	0.196
>3.0	29.116	35.075	3.019	27.655	40.219	5.084	22.792
>2.0	66.064	62.687	92.248	69.397	57.636	88.135	73.344
>1.0	4.618	2.239	4.720	2.703	1.777	6.717	3.658
>0.0	0.000	0.000	0.000	0.023	0.003	0.008	0.010
Bottom	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total							
Percent Occurrence in Each Depth Bin over the Entrance Channel							
Depth bins, ft							Average
>8.0	0.000	0.000	0.000	0.016	0.000	0.000	0.004
>7.0	1.515	0.231	0.000	0.254	0.291	0.074	0.166
>6.0	33.333	23.095	3.651	28.557	39.226	5.982	19.941
>5.0	62.626	76.212	91.074	69.259	58.785	88.022	76.238
>4.0	2.525	0.462	5.269	1.910	1.650	5.852	3.617
>3.0	0.000	0.000	0.006	0.004	0.048	0.067	0.033
>2.0	0.000	0.000	0.000	0.000	0.000	0.004	0.001
>1.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 13 shows, for both the Corps POD and State HDOT underkeel clearance criteria, the percent occurrence of keel motion, while Appendixes C and D show the actual number of occurrences of keel motions for these two underkeel clearance criteria for appropriate corresponding conditions. The percent occurrences of all the virtual markers for all the wave conditions have been included. These results indicate that using the State HDOT criteria could likely result in groundings.

Table 11
Percent Occurrence of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat with Modified Transition for Underkeel Clearance Criteria for Varying Vessel Draft/Water Depth in Channel/Wave Direction Occurrences (Underkeel clearances in the entrance channel and harbor are 1.2 m (4 ft) and 0.6 m (2 ft), respectively)

Vessel draft/water depth in channel/wave direction	41/45/0	43/47/0	39/43/0	41/45/20	43/47/20	39/43/20	
Speed, knots	3.3	3.8	3	3.7	3.5	2.6	
Percent Occurrence in Each Depth Bin over the Harbor							
Depth bins, ft							Average
>8.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>7.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>6.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>5.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>4.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>3.0	0.271	0.000	0.490	0.295	0.622	0.051	0.466
>2.0	28.424	66.667	2.941	28.659	40.590	6.339	6.206
>1.0	67.894	33.333	85.907	69.287	57.101	88.609	83.800
>0.0	3.411	0.000	10.662	1.753	1.687	4.954	9.525
Bottom	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Percent Occurrence in Each Depth Bin over the Entrance Channel							
Depth bins, ft							Average
>8.0	0.000	0.000	0.000	0.012	0.000	0.000	0.003
>7.0	0.000	0.000	0.000	0.024	0.005	0.000	0.006
>6.0	0.000	0.000	0.000	0.131	0.372	0.019	0.102
>5.0	28.571	66.667	0.000	28.715	39.297	1.695	14.189
>4.0	69.870	33.333	97.333	70.068	59.107	95.870	83.717
>3.0	1.558	0.000	2.667	1.050	1.219	2.415	1.983
>2.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>1.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
>0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 12
Percent Occurrence of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat in Entrance Channel for 1.5-m (5-ft) Underkeel Clearance (The four largest waves were run eight times each)

Depth bins, ft	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Average
>8.0	0.009	0.000	0.000	0.006	0.000	0.000	0.000	0.050	0.008
>7.0	0.009	0.013	0.013	0.012	0.000	0.008	0.000	0.010	0.008
>6.0	0.678	0.471	1.033	0.744	0.650	0.721	0.801	0.915	0.752
>5.0	48.965	49.192	48.079	47.045	46.457	49.598	48.537	47.141	48.127
>4.0	49.004	48.277	49.454	51.729	52.286	49.109	49.148	50.920	49.991
>3.0	1.331	2.027	1.309	0.463	0.599	0.564	1.455	0.955	1.088
>2.0	0.004	0.020	0.112	0.000	0.007	0.000	0.017	0.010	0.021
>1.0	0.000	0.000	0.000	0.000	0.000	0.000	0.043	0.000	0.005
>0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bottom	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Study Conclusions

Based on analysis of the physical model data, the following conclusions and recommendations are deduced:

a. The State HDOT underkeel criterion in the harbor does not allow enough clearance for the design vessels to transit into the harbor without possible groundings.

b. The State HDOT and Corps POD criteria in the channel are both conservative, and no groundings or near groundings were found.

c. The recommended underkeel clearance is 0.9 m (3 ft)in the harbor and 1.5 m (5 ft) in the channel for the design vessels studied and for waves less than 2.1 m (7 ft) in height.

d. The transition should be moved to the opening of the harbor basin. At the proposed transition location, there is less wave energy; if vessel shear occurs, the harbor pilot would have more room to react/correct. Model navigation study data support a 0.6-m (2-ft) transition.

Table 13
Percent Occurrence of Keel Motion Through Different Depth Bins for APL C9-Class Containership for Corps POD and State HDOT Underkeel Clearance Criteria with Proposed Transition Location and 4-ft Depth Difference at the Transition

	Corps POD		State HDOT	
Vessel draft/water depth in channel/wave direction	35/43/0 deg	35/43/20 deg	35/41/0 deg	35/41/20 deg
	Average	Average	Average	AverageS
Speed, knots	4.5	4.4	4.4	4.4
Depth bins, ft	Percent Occurrence in Each Depth Bin over the Harbor			
>8.0	0.000	0.000	0.000	0.000
>7.0	0.000	0.000	0.000	0.000
>6.0	0.036	0.002	0.000	0.000
>5.0	1.000	0.419	0.000	0.000
>4.0	49.299	50.085	0.000	0.000
>3.0	48.667	48.477	0.191	0.235
>2.0	0.991	1.017	49.639	52.180
>1.0	0.004	0.000	49.505	46.994
>0.0	0.002	0.000	0.662	0.588
Bottom	0.000	0.000	0.003	0.004
Depth bins, ft	Percent Occurrence in Each Depth Bin over the Entrance Channel			
>8.0	0.000	0.000	0.000	0.000
>7.0	55.011	52.509	0.006	0.002
>6.0	44.525	47.142	0.203	0.128
>5.0	0.464	0.350	53.433	51.261
>4.0	0.000	0.000	45.975	48.248
>3.0	0.000	0.000	0.369	0.361
>2.0	0.000	0.000	0.015	0.000
>1.0	0.000	0.000	0.000	0.000
>0.0	0.000	0.000	0.000	0.000
Bottom	0.000	0.000	0.000	0.000

Appendix A
U.S. Army Engineer Division, Pacific Ocean (POD), Underkeel Clearance Criteria Results for the Modified Bunga Saga Empat Bulk-Cargo Carrier

The following abbreviation codes have been used throughout Appendixes A through F to describe the wave conditions, vessel direction, and run number. In general, two runs were made for each condition.

Abbreviation Code	Wave Condition	Vessel Direction	Run Number
1i1	1	Into harbor	1
1i2	1	Into harbor	2
1u1	1	Out of harbor	1
1u2	1	Out of harbor	2
2i1	2	Into harbor	1
2i2	2	Into harbor	2
2u1	2	Out of harbor	1
2u2	2	Out of harbor	2
3i1	3	Into harbor	1
3i2	3	Into harbor	2
3u1	3	Out of harbor	1
3u2	3	Out of harbor	2
4i1	4	Into harbor	1
4i2	4	Into harbor	2
4u1	4	Out of harbor	1

(continued)

Abbreviation Code	Wave Condition	Vessel Direction	Run Number
4u2	4	Out of harbor	2
5i1	5	Into harbor	1
5i2	5	Into harbor	2
5u1	5	Out of harbor	1
5u2	5	Out of harbor	2
6i1	6	Into harbor	1
6i2	6	Into harbor	2
6u1	6	Out of harbor	1
6u2	6	Out of harbor	2
7i1	7	Into harbor	1
7i2	7	Into harbor	2
7u1	7	Out of harbor	1
7u2	7	Out of harbor	2
8i1	8	Into harbor	1
8i2	8	Into harbor	2
8u1	8	Out of harbor	1
8u2	8	Out of harbor	2
9i1	9	Into harbor	1
9i2	9	Into harbor	2
9u1	9	Out of harbor	1
9u2	9	Out of harbor	2
ai1	10	Into harbor	1
ai2	10	Into harbor	2
au1	10	Out of harbor	1
au2	10	Out of harbor	2
bi1	11	Into harbor	1
bi2	11	Into harbor	2
bu1	11	Out of harbor	1
bu2	11	Out of harbor	2
ci1	12	Into harbor	1
ci2	12	Into harbor	2
cu1	12	Out of harbor	1
cu2	12	Out of harbor	2

The tables are divided into three parts for ease of use. The vessel speed is given at the top of the table, followed by the number of occurrences in the harbor, and then followed by the number of occurrences in the entrance channel.

The average vessel speed is given as a vector quantity based upon the coordinate convention shown in Figures 19 and 20 of the main text. For the average speed calculated for a given condition, the absolute value of the speed was used. The number of occurrences is calculated by summing each occurrence of each virtual marker at each instant in time. This is different from the body of the report where the percent of occurrence is reported.

Table A1

Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for Corps POD Underkeel Clearance Criteria for 36-ft Vessel Draft, 44-ft Entrance-Channel Depth, 40-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2	7i1
Vessel speed, knots		-4.9	4.1	3.8	-4.9	-5	4.1	3.7	-4.9	-4.8	4.1	4	-4.9	-5	4.1	3.9	-5		3.8	4.1	0	-4.7	4	3.9	-5
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								
>8.0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>7.0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>6.0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>5.0		0	0	2	0	0	0	0	1	0	0	17	0	0	0	0	0		17	0	0	0	1	2	0
>4.0		385	376	521	437	451	397	628	451	331	206	502	426	487	289	339	347		427	469	353	540	331	498	369
>3.0		2446	2791	3373	2402	2488	2851	3316	2296	2530	3277	3049	2369	2438	3171	3189	2361		3115	2797	2376	2434	2838	3117	2121
>2.0		36	6	20	11	29	11	15	22	17	3	9	2	18	8	0	20		7	0	1	6	14	1	19
>1.0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>0.0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
Bottom		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																								
>8.0		65	209	196	19	82	182	342	71	7	147	282	5	56	370	241	84		238	223	32	52	394	223	77
>7.0		779	1607	1757	554	897	1670	1686	796	750	1635	1572	504	904	1569	1639	605		1641	1539	609	822	1514	1383	726
>6.0		0	0	2	0	1	10	8	2	0	0	2	0	0	6	0	0		13	0	1	0	20	0	0
>5.0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>4.0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>3.0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>2.0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>1.0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>0.0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
Bottom		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0

(Continued)

Table A1 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-5	-4.8	4	4	-4.9	-4.8	3.8	3.9	-4.7	-4.8	3.9	4.1	-4.8	-4.8	4.3	4	-4.7	-4.8	4.3	4.2	-5.1	-4.8	4.4	4.2	4.18
Depth bins, ft	Number of Occurrences in Each Bin over the Harbor																								Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	3	0	0	1	0	0	8	0	0	0	0	0	0	1	0	0	6	0	0	0	0	0	59
>4.0	369	481	402	390	246	425	490	409	381	286	407	368	377	630	403	474	334	513	376	318	438	580	587	423	19298
>3.0	2121	2511	2867	3043	2264	2536	2641	2899	2649	2660	3166	2845	2554	2171	2742	3032	2505	2393	2703	3003	2492	2019	2594	2725	124159
>2.0	19	4	5	0	34	20	0	0	14	12	15	2	34	4	15	3	26	8	0	0	29	17	3	8	528
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth bin over the Entrance Channel																								
>8.0	77	23	313	468	18	40	338	225	14	19	355	215	39	146	295	409	48	20	239	280	154	107	256	532	8150
>7.0	726	642	1702	1425	482	713	1710	1581	530	905	1608	1486	741	601	1438	1488	771	795	1400	1608	640	685	1363	1286	52758
>6.0	0	0	35	72	0	0	15	4	0	0	20	0	0	0	0	35	0	0	7	38	0	0	3	51	345
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A2
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for Corps POD Underkeel Clearance Criteria for 36-ft Vessel Draft, 44-ft Entrance-Channel Depth, 40-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-5	-4.5	4.4	4.1	-5	-4.9	4.2	4	-5.3	-4.7	4.5	4.3	-4.8	-4.9	4.3	4.5	-4.8	-4.6	4.3	4.4	-4.7	-4.6	4.1	4.2
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	1	1	0	0	3	0	0	0	1	1	2	0	0	0	0	0	3	6	0	0	0	5	0	0
>4.0	464	435	45	21	437	397	38	18	540	470	86	45	481	433	136	63	470	484	155	89	411	464	70	156
>3.0	1530	1932	741	458	1672	1768	598	488	1589	1702	807	653	1730	1684	791	717	1781	1736	706	748	1907	1484	768	924
>2.0	77	95	4	0	94	76	0	0	136	93	3	1	110	85	1	0	89	97	2	2	84	71	0	1
>1.0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																							
>8.0	62	137	396	501	86	83	308	319	64	98	288	502	70	90	307	470	112	76	346	390	108	128	423	405
>7.0	938	1089	2082	2089	900	997	2228	2302	960	894	2068	1979	1047	996	2102	1866	955	1033	2138	2120	885	1214	2218	2032
>6.0	0	1	14	32	0	3	31	11	0	0	25	29	0	0	28	74	0	0	31	23	1	0	25	22
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

Table A2 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.7	-4.8	4.4	4.3	-4.8	-4.8	4.3	4.5	-4.7	-4.7	4.2	4.4	-4.5	-4.4	4.2	4.2	-4.8	-4.8	4.4	4.3	-4.8	-4.5	4.6	4.3	4.37
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	1	5	0	0	4	3	0	0	3	0	0	0	2	0	0	0	0	2	0	0	3	8	0	0	54
>4.0	502	493	53	64	403	435	79	107	414	423	164	81	651	567	86	52	337	622	53	169	581	666	94	196	13700
>3.0	1782	1739	839	494	1744	1779	793	593	1841	1842	1135	449	1798	1896	675	607	1905	1694	899	480	1783	1726	759	650	58816
>2.0	94	104	2	0	61	71	0	0	71	80	5	0	101	78	0	0	54	103	7	0	89	84	1	5	2131
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																								
>8.0	81	110	453	441	81	96	566	313	108	67	406	370	70	163	566	518	324	108	417	427	126	170	662	618	13030
>7.0	873	910	2043	2131	995	1084	1949	2035	977	1037	1989	2062	898	917	1990	2021	706	914	1851	2078	825	795	1676	1829	71717
>6.0	0	2	6	26	0	0	84	9	0	1	15	26	2	0	77	63	9	1	61	13	4	1	90	38	878
>5.0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A3
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for Corps POD Underkeel Clearance Criteria for 34-ft Vessel Draft, 42-ft Entrance-Channel Depth, 38-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-5.1	-4.9	4.3	4	-5.2	-4.9	0	4.1	-4.9	-5.1	4.4	4.2	-5.1	-5.1	4.1	4.3	-5	-5.1	4.2	4.5	-4.9	-5	4.4	4.5
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	22	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	40	0	1	0	0	25	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
>4.0	281	310	203	109	385	300	141	145	285	192	160	144	272	265	168	99	237	199	148	122	211	363	160	103
>3.0	3386	2985	3065	3065	3165	3062	2652	2865	3166	3064	2950	2854	2870	3051	2865	2846	3100	3444	2906	2849	3005	3417	2723	2853
>2.0	62	75	23	38	113	139	21	12	64	68	29	41	62	68	27	6	79	44	35	34	59	82	12	10
>1.0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																							
>8.0	22	26	184	229	22	13	134	178	21	7	233	176	15	22	158	223	24	22	124	197	41	40	238	166
>7.0	909	792	1772	1856	886	797	2285	1932	845	869	1728	1885	868	804	1874	1770	874	791	1930	1803	799	768	1743	1722
>6.0	0	0	94	127	2	0	36	79	1	0	69	116	0	1	86	113	0	0	74	67	2	1	74	75
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

Table A3 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.8	-4.8	4.3	4.3	-4.9	-4.9	4.4	4.2	-5	-4.8	4.4	4.3	-5	-5	4.4	4.3	-4.6	-5	4.5	4.2	-5	-5	4.2	4.4	4.38
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	52
>5.0	0	0	0	0	0	5	0	36	0	0	0	0	0	0	0	0	0	0	23	0	0	3	0	0	134
>4.0	212	237	51	174	360	284	172	369	335	322	105	300	281	341	186	289	308	252	192	169	283	350	181	324	11079
>3.0	3090	3387	3036	2974	3198	3267	2811	2548	3205	3274	2822	2829	3182	3206	2679	2900	3205	2990	2750	2757	3200	3252	2969	2828	144567
>2.0	67	74	4	19	80	46	72	93	60	107	76	66	80	71	12	104	128	82	48	24	31	83	55	60	2745
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																								
>8.0	38	10	233	265	22	24	201	291	32	66	196	230	24	76	217	246	61	52	149	243	37	106	211	179	5724
>7.0	868	885	1796	1767	805	808	1852	1739	792	873	1818	1738	839	790	1774	1620	709	790	1778	1850	874	799	1808	1741	63415
>6.0	0	0	88	75	3	0	45	129	5	0	81	96	1	3	61	166	0	1	57	90	5	0	86	106	2115
>5.0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	11	0	0	0	0	0	0	0	0	14
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A4

Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for Corps POD Underkeel Clearance Criteria for 34-ft Vessel Draft, 42-ft Entrance-Channel Depth, 38-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-5	-5.1	4.2	4.3	-5	-4.8	4.6	4.4	-5.1	-5	4.5	4.5	-5.1	-5	4.4	4.6	-5	-5	4.6	4.5	-5.7	-5	4.2	4.6
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	2	0	0	3	0	0	0	0	0	5	4	0	0	0	0	0	0	0	0	0
>4.0	220	267	138	148	275	200	139	143	203	267	110	164	205	299	169	151	278	226	122	121	259	339	94	89
>3.0	3068	3208	3022	2908	3151	3230	2815	2747	2916	3037	2652	2790	3030	3000	2597	2222	3047	3138	2500	2306	3003	3151	2752	2101
>2.0	67	84	4	6	99	114	25	3	81	28	27	50	102	56	15	52	62	48	2	32	75	73	36	30
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																							
>8.0	5	21	180	114	31	33	102	201	31	34	162	196	39	43	191	224	18	18	181	203	32	46	118	116
>7.0	789	722	1860	1877	775	821	1686	1789	824	873	1791	1750	845	786	1820	1630	719	748	1743	1752	864	744	1925	1807
>6.0	0	0	78	70	0	0	103	100	3	0	61	43	0	2	51	97	1	0	27	74	0	6	27	78
>5.0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

Table A4 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-5	-5	4.4	4.5	-5	-5.1	4.5	4.3	-5	-5	4.2	4.3	-4.8	-4.6	4.4	4.5	-4.9	-5.2	4.6	4.6	-5	-5	4.6	4.6	4.56
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	7	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	1	0	0	1	0	6	0	32
>4.0	230	267	87	47	303	271	208	146	199	191	126	103	319	266	133	117	451	366	68	57	285	293	222	127	9508
>3.0	2957	2851	2796	2183	3060	2804	2590	2385	2991	3005	2792	2127	3183	2974	2724	2268	2856	3120	2710	2312	2898	2692	2395	2098	133162
>2.0	86	69	24	13	88	78	87	19	70	43	47	37	68	96	23	6	110	55	25	43	95	71	90	27	2541
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																								
>8.0	42	31	171	154	46	55	158	208	46	19	251	111	69	32	194	170	75	34	140	147	33	109	239	224	5097
>7.0	809	705	1731	1838	739	790	1711	1851	716	854	1901	1845	948	838	1702	1709	734	733	1641	1666	665	686	1578	1617	60947
>6.0	0	7	24	55	0	1	70	60	0	1	71	40	0	5	118	82	3	8	88	118	6	4	47	143	1772
>5.0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	19
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A5
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for Corps POD Underkeel Clearance Criteria for 39-ft Vessel Draft, 47-ft Entrance-Channel Depth, 43-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-4.6	-4.7	4.5	4.1	-4.7	-4.7	4.4	4	-4.7	-4.7	3.9	4.3	-4.5	-5	4.1	4	-4.4	-4.7	4.5	4.4	-4.7	-4.5	4.1	4.3
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	9	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	203	132	35	48	168	160	45	59	212	197	65	40	114	59	65	76	186	124	34	24	167	89	53	49
>3.0	1770	1518	941	776	1812	1710	584	812	1847	1888	569	1236	1808	724	1047	460	1745	1137	790	628	1808	1188	702	942
>2.0	156	170	39	67	149	162	27	58	162	164	72	118	175	81	41	84	127	141	37	37	122	79	141	77
>1.0	3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																							
>8.0	24	9	89	128	18	22	158	205	8	49	149	79	22	8	119	115	47	28	73	70	36	19	123	42
>7.0	627	547	1880	1503	523	605	1908	1969	606	738	1965	1682	521	345	2018	977	738	728	1697	801	784	634	1623	1126
>6.0	46	9	99	58	33	10	167	158	45	12	239	105	18	19	150	33	36	22	108	36	43	48	73	14
>5.0	0	0	0	3	0	0	3	0	0	0	5	1	0	0	0	1	1	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

Table A5 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.9	-4.4	4.5	4.1	-4.8	-4.3	4.1	4.2	-4.6	-4.4	4	4.5	-4	-4.6	3.8	4.3	-4.5	-5	4.1	4.4	-4.6	-5	4.1	3.9	4.22
Depth bins, ft	Number of Occurrences in Each Bin over the Harbor																								Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	5	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	20
>4.0	125	143	73	25	274	184	44	33	142	124	86	118	14	268	7	72	137	66	46	56	224	81	97	30	4873
>3.0	1451	2035	773	896	1663	1797	664	1187	1359	1975	620	1068	828	1703	729	1313	1394	956	501	1142	1437	892	801	852	56478
>2.0	214	113	94	149	182	164	52	79	122	110	79	140	110	153	37	318	197	76	55	87	182	100	132	69	5500
>1.0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	4	1	0	0	0	0	0	0	14
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Bin over the Entrance Channel																								
>8.0	34	5	143	36	54	40	111	112	60	9	156	278	20	30	148	107	117	44	80	170	33	31	180	14	3652
>7.0	530	570	1430	991	583	704	2165	1924	547	672	803	1622	392	547	1392	1773	843	376	600	1750	739	253	1429	505	49685
>6.0	16	35	64	18	25	36	126	121	19	25	39	210	19	29	117	100	59	44	14	142	46	47	121	12	3065
>5.0	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	6	0	0	0	10	0	0	0	0	49
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A6
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for Corps POD Underkeel Clearance Criteria for 39-ft Vessel Draft, 47-ft Entrance-Channel Depth, 43-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-4	-4.4	4.2	4.3	-4	-4.2	4.4	4.1	-5	-4.4	4.2		-4.4		4.1	4.2	-4.4	-4.4	4	4.2	-4.5	-4.5	4.1	4.1
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0		0		0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0		0		0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0		0		0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	1	0	0		0		5	0	4	4	0	0	0	0	0	0
>4.0	42	93	19	34	37	169	28	83	51	102	55		151		96	77	180	180	44	52	117	117	67	67
>3.0	754	1519	930	795	826	1463	267	1292	817	1777	433		1678		904	1097	1781	1781	770	1462	1629	1629	1292	1292
>2.0	101	208	37	61	136	243	64	179	91	114	40		182		119	68	169	169	61	159	243	243	110	110
>1.0	1	2	0	0	0	7	0	1	0	0	0		0		0	0	0	0	0	0	3	3	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0		0		0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0		0		0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																							
>8.0	9	11	81	91	19	23	47	75	14	14	63		12		58	160	50	50	60	185	51	51	146	146
>7.0	244	492	1689	1834	222	559	747	1632	349	674	687		432		610	1633	866	866	2019	1475	556	556	1632	1632
>6.0	16	27	76	128	44	43	20	92	44	19	27		21		26	147	58	58	65	86	35	35	168	168
>5.0	0	0	0	0	0	1	0	0	1	0	0		0		0	1	0	0	1	3	0	0	4	4
>4.0	0	0	0	0	0	0	0	0	0	0	0		0		0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0		0		0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0		0		0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0		0		0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0		0		0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0		0		0	0	0	0	0	0	0	0	0	0

(Continued)

Table A6 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.7	-4.7	4	4	-4.4	-4.6	4.2	4.2	-4.4	-4.6	4.1	4.3	-4.4	-4.5	4.4	4.4	-4.8	-4.8	4.1	4.4	-4.1	-4.7	4.1	4.4	4.17
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1	1	0	0	0	0	0	1	20
>4.0	142	142	86	86	154	259	70	70	194	133	48	46	203	113	74	74	97	97	60	233	222	153	105	159	4881
>3.0	1572	1572	1079	1079	1874	1475	1382	1382	1728	1780	973	1090	1783	1467	1140	1140	1746	1746	1541	923	1693	1598	1443	1075	60469
>2.0	190	190	168	168	164	208	191	191	160	206	62	146	210	148	120	120	155	155	109	395	192	176	161	165	7057
>1.0	3	3	0	0	1	5	0	0	0	0	0	1	0	15	0	0	0	0	0	4	0	0	0	0	49
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																								
>8.0	42	42	96	96	27	33	92	92	98	52	176	199	121	64	94	94	32	32	118	217	68	29	120	192	3642
>7.0	542	542	1718	1718	718	653	1562	1562	1032	786	1914	1481	1182	566	1476	1476	540	540	1455	1346	962	435	1452	1330	48394
>6.0	20	20	72	72	32	37	84	84	38	37	177	106	115	48	125	125	25	25	136	195	58	85	181	191	3491
>5.0	0	0	0	0	0	0	0	0	0	0	4	0	1	0	3	3	0	0	1	17	0	2	3	1	50
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A7
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for Corps POD Underkeel Clearance Criteria for 41-ft Vessel Draft, 49-ft Entrance-Channel Depth, 45-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-4.7	-4.2	4.8	4.1	-4.4	-4.5	4.4	4.5	-4.8	-4.2	4.3	4.2	-4.3	-4.5	4.3	4.2	-4.5	-4.2	4.5	4	-4.5	-4.4	4.2	4.4
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	3	0	1	1	2	2	2	4	5	0	0	1	1	0	0	1	11	0	0	10	29	0	0
>4.0	710	740	289	678	677	610	326	434	745	754	253	323	776	550	375	395	699	602	363	383	737	668	420	498
>3.0	1706	1671	1319	1565	1567	1515	909	1286	1415	1824	1259	955	1623	1224	981	1467	1536	1189	1147	1098	1544	1494	1403	1186
>2.0	31	38	14	61	30	12	39	92	40	66	12	9	47	35	11	40	18	24	19	30	40	41	26	25
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																							
>8.0	138	195	736	339	177	246	666	419	362	189	576	428	322	237	417	262	311	186	636	500	276	288	549	455
>7.0	715	610	997	1230	500	680	1256	1019	825	492	1285	1210	745	535	1250	888	856	575	1108	972	714	659	1198	1186
>6.0	16	1	29	2	0	4	48	3	5	0	38	33	8	1	44	2	11	5	27	8	5	4	16	1
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

Table A7 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.7	-4.6	4.2	4	-4.3	-4.4	4.8	4.3	-4.3	-4.3	4.3	4.1	-4.3	-4.7	4.3	4.4	-4.7	-4.6	4.2	4.2	-4.5	-4.6	3.9	4.3	4.21
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	4	0	0	12	6	6	0	2	0	1	0	0	0	10	0	1	4	22	0	0	0	0	1	1	143
>4.0	719	541	476	479	737	597	334	512	574	602	498	117	728	635	662	414	719	668	494	494	527	707	813	487	26539
>3.0	1592	1573	1319	1032	1560	1754	1044	1115	1498	1635	1137	652	1598	1534	1591	992	1592	1584	1275	1275	1453	1459	1584	994	65725
>2.0	29	22	37	27	43	53	26	55	41	35	32	17	62	56	91	17	29	53	41	41	44	80	85	7	1823
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	3
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																								
>8.0	233	377	590	465	342	150	478	490	252	123	576	576	212	237	595	650	233	252	598	598	279	216	541	511	18484
>7.0	878	518	1246	1277	952	669	1188	1228	685	559	1181	1272	752	382	957	1273	878	463	1238	1238	932	660	1143	1483	44557
>6.0	10	5	37	11	22	20	23	6	4	0	9	27	17	2	16	19	10	16	41	41	2	9	8	27	693
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A8
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for Corps POD Underkeel Clearance Criteria for 41-ft Vessel Draft, 49-ft Entrance-Channel Depth, 45-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-5	-5	4.1	4.2	-5	-5	4.6	4.3	-4.8	-4.9	4.2	4.2	-4.9	-4.5	4.1	4.4	-4.8	-4.3	4.1	4.3	-4.7	-4.6	4	4.3
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	2	2	11	0	1	1	6	14	0	4	0	1	0	7	3	9	0	0	0	0	1	0	12	6
>4.0	526	526	481	298	432	432	404	436	453	421	494	244	556	472	554	237	672	390	969	259	543	445	569	255
>3.0	1132	1132	1280	940	996	996	958	968	1265	948	1137	581	1334	1167	1319	444	1401	1008	1614	419	1220	1134	1206	427
>2.0	55	55	11	76	40	40	5	17	58	65	26	27	84	56	51	24	57	41	77	20	23	35	83	73
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each depth Bin over the Entrance Channel																							
>8.0	309	309	544	584	250	250	513	567	182	208	487	386	188	168	505	409	126	199	446	430	319	263	506	489
>7.0	479	479	1091	962	535	535	1014	877	472	429	1116	1030	415	479	1089	901	439	528	1041	867	562	530	1183	501
>6.0	17	17	65	20	5	5	40	10	17	4	67	20	2	6	58	10	23	8	90	18	2	11	43	55
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

Table A8 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.8	-5	4.6	4.5	-4.7	-4.8	4.3	4.2	-4.7	-4.5	3.9	4.6	-4.6	-4.7	4.4	4.3	-4.6	-4.8	4.5	4.4	-4.6	-4.5	4.4	4.4	4.34
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	1	0	2	23	0	18	8	11	8	0	2	8	0	7	12	2	6	2	0	6	3	0	199
>4.0	644	445	498	308	716	757	313	411	420	678	502	364	455	628	277	576	496	700	356	422	398	600	380	373	22785
>3.0	1402	1036	962	747	1304	1435	1097	581	971	1334	1397	833	1109	1538	498	1220	1090	1616	1003	962	1111	1586	459	1235	51552
>2.0	98	39	29	35	47	64	15	111	43	85	67	49	63	31	1	28	73	26	39	20	72	58	65	15	2272
>1.0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																								
>8.0	160	153	493	542	193	261	495	628	170	121	512	625	223	158	381	446	157	286	452	736	151	174	611	529	17294
>7.0	573	434	1131	821	593	490	1037	841	500	546	1214	1017	509	569	769	1035	352	470	789	917	452	568	725	1076	34982
>6.0	6	11	33	33	1	21	34	46	6	30	32	79	6	17	36	27	4	29	13	76	12	11	46	15	1237
>5.0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	6
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix B Hawaii Department of Transportation (HDOT) Underkeel Clearance Criteria Results for the Modified Bunga Saga Empat Bulk-Cargo Carrier

See Appendix A for description of tables.

Table B1
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for State HDOT Underkeel Clearance Criteria for 38-ft Vessel Draft, 44-ft Entrance-Channel Depth, 40-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-4.5	-4.9	3.5	3.9	-4.3	-5	3.2	3.7	-4.4	-4.9	3.7	3.9	-4.6	-5	3.9	4	-4.4	-4.7	3.6	4	-4.7	-4.9	3.7	4.1
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	2	3	0	0	0	0	4	0	0	1	0	0	0	0	0	0	0	3	0	0	0
>2.0	266	205	149	139	278	180	190	26	274	96	180	33	350	216	108	33	282	125	107	54	269	167	107	137
>1.0	2574	1656	2088	1486	2539	1631	2290	530	2487	896	2183	513	2273	1745	2256	586	2673	972	1794	1567	2240	1748	2146	1627
>0.0	7	21	1	3	18	21	8	0	14	1	9	1	8	25	20	6	8	2	1	0	2	12	1	3
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
>6.0	39	19	166	125	53	46	135	98	19	48	157	146	59	14	175	160	119	19	182	227	71	80	215	292
>5.0	916	637	1917	1694	1032	874	2101	628	897	229	1841	589	912	981	1817	882	961	343	2040	2187	814	501	1934	1735
>4.0	2	0	34	25	1	0	1	11	0	1	10	8	3	0	1	28	4	0	1	24	0	0	3	91
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

Table B1 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.2	-4.8	3.3	3.6	-4.6	-4.7	3.4	4.1	-4.8	-4.8	3.7	4	-4.7	-4.8	3.6	3.9	-4.8				-4.7				4.05
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0				0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0				0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0				0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0				0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0				0
>3.0	0	0	0	0	0	0	0	0	5	0	0	0	1	1	0	0	0				2				22
>2.0	259	241	305	82	237	183	241	111	239	195	114	144	269	304	239	122	317				338				7911
>1.0	2595	1620	2541	1634	2517	1874	2304	1759	2339	1768	2055	1792	2259	1655	2021	1838	2377				2256				79704
>0.0	12	9	24	11	1	15	10	10	28	15	7	23	8	24	29	11	21				25				475
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0				0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																								
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0				0
>7.0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	2				0				10
>6.0	84	67	126	228	53	14	250	344	40	38	216	316	74	9	203	272	87				65				5150
>5.0	946	541	1877	1871	923	719	1911	1627	862	653	2046	1579	859	480	1963	1852	712				845				50728
>4.0	1	0	2	39	1	0	17	49	0	0	5	58	1	2	0	45	0				3				471
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0				0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0				0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0				0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0				0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0				0

Table B2
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for State HDOT Underkeel Clearance Criteria for 38-ft Vessel Draft, 44-ft Entrance-Channel Depth, 40-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-4.7	-4.6	4	4.1	-4.7	-4.6	4.4	4.3	-4.6	-4.9	4.4	4.4	-4.8	-4.4	4.4	4.2	-4.5	-4.5	4	4.1	-4	-4.3	4.2	4.4
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
>2.0	292	443	351	302	448	542	302	232	468	397	330	104	481	392	264	305	475	458	318	276	53	443	55	301
>1.0	3533	3254	2966	2400	3403	3209	2849	2385	3376	3278	2864	2477	3436	3405	2956	2477	3412	3423	2954	2444	970	3275	744	2216
>0.0	11	67	47	1	25	45	1	4	31	17	17	0	28	22	4	9	27	15	30	16	0	59	0	35
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	1	0	0	0	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	81	30	396	364	19	19	240	312	64	46	304	276	95	92	347	293	36	31	380	318	6	22	61	312
>5.0	826	892	1767	1723	908	820	1650	1862	825	695	1709	1742	697	722	1689	1830	784	798	1720	1911	60	784	991	1668
>4.0	0	0	74	40	0	0	31	22	0	0	34	56	0	0	59	57	0	0	56	46	0	0	15	58
>3.0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

Table B2 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.6	-4.5	4	4.4	-4.6	-4.5	4.2	4.4	-4.5	-4.5	4.3	4.1	-4.3	-4.3	4.2	3.9	-4.6	-4.7	3.6	4.3	-4.4	-4.6	4.3	4.2	4.2
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	1	0	0	0	5
>2.0	92	408	79	201	100	451	54	235	24	363	28	273	15	393	59	429	29	520	51	423	103	513	336	336	13547
>1.0	876	3307	993	2201	1092	3358	457	2368	285	3440	303	2361	227	3444	406	2696	203	3306	361	2347	671	3238	2917	2308	110871
>0.0	3	27	4	14	0	43	4	14	0	29	0	42	0	46	1	14	0	38	0	38	3	94	9	29	963
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																								
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	11
>6.0	12	187	86	344	4	47	14	292	1	19	20	410	4	47	20	329	4	54	19	390	20	68	362	444	7341
>5.0	22	561	992	1723	67	688	239	1856	8	835	338	1891	23	763	258	1860	8	774	332	1655	54	602	1635	1774	48031
>4.0	0	0	3	62	0	0	0	59	0	0	1	91	1	2	0	56	0	1	0	69	0	0	66	65	1024
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	10	0	0	0	0	13
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table B3
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for State HDOT Underkeel Clearance Criteria for 36-ft Vessel Draft, 42-ft Entrance-Channel Depth, 38-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-4.7	-4.7	3.9	4.1	-4.6	-4.9	3.9	4.1	-4.6	-4.7	3.9	4.1	-4.6	-4.8	4	4	-4.9	-4.7	4.1	4.2	-4.7	-4.9	4	3
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	3	0	0	0	11	0	0	0	1	0	0	10	0	0	0	0	0	0	0
>2.0	505	538	374	288	518	591	410	335	527	473	449	239	519	533	445	341	543	568	310	428	508	565	319	357
>1.0	2949	2748	2622	2311	2972	2725	2787	2789	2936	2881	3062	2794	3116	2905	2629	2659	2969	2875	2774	2696	3005	2838	2923	2862
>0.0	64	15	3	0	27	17	0	11	47	70	7	0	67	39	9	1	50	19	0	35	24	43	5	3
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	5	1	0	0	0	3	2	0	0	0	0	0	4	5	0	0	0	4	0	0	3	1	0	0
>6.0	143	102	298	414	66	137	301	350	102	112	525	318	142	159	292	499	99	169	379	531	153	310	344	418
>5.0	780	763	1971	1821	914	803	1853	1689	918	941	1621	1734	847	774	1815	1653	753	889	1738	1573	774	701	1761	1666
>4.0	0	0	12	64	0	0	5	28	0	0	24	12	0	0	0	28	0	0	25	80	0	0	67	33
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

Table B3 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.6	-4.7		4.1	-4.8	-4.8	3.8	4	-4.7	-4.8	4.1	4	-4.6	-4.6	4	4.1	-4.7	-4.4	4.1	4.1	-4.8	-4.8	4	4.3	4.2
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								Total
>8.0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0		0	0	0	0	0	0	0	0	0	3	7	0	0	1	1	7	0	1	0	0	1	46
>2.0	542	560		357	524	452	454	579	502	574	394	371	515	783	344	283	680	556	295	307	741	515	532	439	21982
>1.0	3027	2635		2746	2953	2697	2897	2465	3247	2804	2674	2786	3163	2620	2840	2660	2976	2942	2627	2696	2888	2894	2609	2276	131949
>0.0	13	69		0	28	23	2	8	28	15	13	8	34	79	2	1	54	44	0	3	28	16	24	10	1058
Bottom	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																								
>8.0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	3
>7.0	0	14		0	8	0	11	0	0	2	0	0	7	0	2	0	2	0	2	0	0	3	0	4	83
>6.0	98	255		370	248	145	549	331	73	248	498	397	157	94	491	428	108	233	418	412	135	280	559	463	13353
>5.0	904	685		1790	640	802	1603	1904	770	845	1570	1702	833	960	1718	1572	850	829	1767	1623	698	510	1542	1555	58424
>4.0	0	0		29	0	0	33	18	0	0	80	44	1	2	67	57	0	3	38	76	0	0	83	10	919
>3.0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	0	14
>2.0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table B4
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for State HDOT Underkeel Clearance Criteria for 36-ft Vessel Draft, 42-ft Entrance-Channel Depth, 38-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-4.6	-4.6	4.2	4.2	-4.6	-4.7	4.5	4.8	-4.7	-4.8	4.3	4.7	-4.8		4.2	4.5	-4.6	-4.9	4.5	4.4	-4.6	-4.7	4.5	4.5
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	4	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	2	10	0	0
>2.0	440	423	138	92	413	290	176	75	446	276	168	107	421	429	181	119	491	334	130	85	453	442	155	86
>1.0	2378	2456	1271	677	2491	2547	1376	607	2347	2533	1145	661	2401	1354	1304	893	2526	2434	1168	782	2573	2349	1033	678
>0.0	20	17	0	0	20	33	1	1	21	9	0	13	10	32	1	0	7	13	3	5	40	18	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
>6.0	128	129	412	368	106	130	330	459	125	240	370	467	168	658	376	322	182	103	321	328	162	117	367	243
>5.0	651	692	1631	1172	677	705	1693	1251	626	684	1739	1461	686	1222	1601	1583	562	759	1579	1496	744	652	1511	1585
>4.0	1	0	13	32	0	2	26	64	0	2	58	53	1	109	41	32	0	10	88	61	1	0	9	8
>3.0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

Table B4 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.6		4.5		-4.7	-4.8	4.2	4.4	-4.6	-4.6	4.5	4.6	-4.7	-4.8	4.4	4.3	-4.6	-4.5	4.4	4.6	-4.6	-4.6	4.4	4.7	4.38
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								Total
>8.0	0		0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0		0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0		0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0		0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0		0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0		0		4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	6	3	0	35
>2.0	447		160		469	428	278	202	420	499	183	228	449	492	195	130	469	529	278	197	567	532	231	182	13935
>1.0	2289		1580		2141	2474	1488	959	2387	2479	1597	903	2376	2297	1043	844	2394	2304	1168	675	2415	2423	1253	795	78268
>0.0	25		4		10	11	7	3	12	42	0	4	10	19	1	3	29	22	0	38	41	11	1	6	563
Bottom	0		0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																								
>8.0	0		0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0		0		0	2	0	0	0	3	0	0	0	0	0	0	0	0	0	1	0	0	0	0	9
>6.0	145		351		87	152	422	443	102	157	354	254	106	85	458	367	80	168	381	408	189	140	383	460	12303
>5.0	565		1625		629	557	1548	1425	722	716	1626	1649	614	607	1365	1596	531	704	1572	1497	567	619	1620	1316	50632
>4.0	0		27		2	1	34	62	1	1	38	22	5	7	49	47	4	2	57	56	0	10	7	43	1086
>3.0	0		0		0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
>2.0	0		0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0		0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0		0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0		0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table B5
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for State HDOT Underkeel Clearance Criteria for 41-ft Vessel Draft, 47-ft Entrance-Channel Depth, 43-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-4.3	-4.6	3.7	3.6	-4.4	-4.6	4.3	3.4	-4.6	-4.6	3.6	3.3	-4.3	-4.2	4	2.9	-4.5	-4.9	4.1	4.1	-4.5	-4.5	3.6	4
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	13	2	1	8	0	6	21	0	1	2	0	1	0	0	0	0	1	2	0	0	13	0	0	0
>2.0	547	617	560	599	507	628	395	460	611	535	559	493	758	543	601	590	578	649	435	278	591	513	194	897
>1.0	1566	1621	995	1236	1340	1372	1301	909	1544	1672	1117	1468	1706	1424	874	2163	1550	1489	1275	731	1379	1177	889	1435
>0.0	36	27	36	28	47	67	25	7	14	34	18	16	36	4	14	19	5	30	22	8	36	24	7	45
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
>7.0	0	0	0	3	2	0	0	1	0	0	3	5	0	0	1	5	0	0	3	2	0	0	0	0
>6.0	165	140	700	680	154	239	586	668	170	174	630	665	77	125	567	629	145	194	775	794	112	156	638	555
>5.0	538	485	1656	1506	662	760	1217	1733	670	550	1620	1700	438	627	1581	1880	538	670	1295	1476	505	545	1654	875
>4.0	0	6	36	65	27	0	19	59	8	30	43	32	0	1	13	48	3	8	38	50	7	18	21	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

Table B5 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.5	-4.7	4.5	3.3	-4.8	-4.6	4.3	3.2	-4.5	-4.5	3.9	3.9	-4.4	-4.4	4.3	2.5	-4.6	-4.5	4.2	4.1	-4.3	-4.3	3.9	4.2	4
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	6	1	0	0	1	6	0	11	2	1	2	0	1	10	0	0	15	1	0	0	5	14	0	7	154
>2.0	646	729	151	356	715	620	346	835	860	580	339	455	620	704	286	166	608	446	349	484	597	640	425	568	25663
>1.0	1539	1824	624	1028	1515	1059	603	1491	1486	1370	603	1662	1475	1517	654	386	1358	1693	824	1388	1624	1514	729	1103	61302
>0.0	28	77	27	31	33	14	13	113	69	13	17	34	41	8	24	11	43	20	14	40	43	15	20	71	1424
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																								
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
>7.0	0	0	7	10	5	0	29	3	1	0	4	13	0	0	14	8	0	0	3	3	0	0	0	5	130
>6.0	140	107	764	597	255	182	804	832	104	147	743	632	166	228	721	633	150	131	674	729	117	276	665	713	20248
>5.0	603	274	1273	1523	549	683	1223	1671	496	591	1552	1339	606	646	1435	1169	568	634	1438	1393	463	597	1671	1112	48690
>4.0	1	3	71	61	19	4	80	99	6	7	67	26	4	1	112	42	12	11	37	83	10	7	32	92	1419
>3.0	0	0	14	0	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	1	1	28
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table B6
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for State HDOT Underkeel Clearance Criteria for 41-ft Vessel Draft, 47-ft Entrance-Channel Depth, 43-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-4.4	-4.6	3.6	3.3	-4.6	-4.5	3.5	3.5	-4.8	-4.4	3.3	2.1	-4.5	-4.5	3.3	3.4	-4.4	-4.3	2.7	3.2	-4.3	-4.4	3.2	3.2
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	5	1	0	0	0	3	0	0	0	8	2	0	2	1	2	2	0	1	1	0	0	0	2	0
>2.0	623	531	413	428	562	583	326	351	511	523	571	560	507	534	591	370	561	608	438	424	628	543	502	489
>1.0	1076	1122	731	1179	1217	1214	944	784	1233	1231	1173	1115	1363	1252	1375	917	1246	1272	1201	966	1149	1098	1216	1321
>0.0	43	90	20	54	58	88	14	27	44	82	71	31	86	55	128	8	44	49	19	11	76	91	21	22
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																							
>8.0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	1	0	2	1	0	0	0	1	0	4	1	0	0	0	19	0	0	4	3	2	0	3	5	3
>6.0	117	245	454	393	146	163	526	498	228	225	478	465	95	160	596	565	99	171	453	574	96	98	626	413
>5.0	667	415	1597	1598	435	443	1371	1552	443	469	1607	1219	395	447	1350	1438	463	508	1300	1479	385	357	1374	1583
>4.0	42	11	8	7	12	14	8	51	22	11	33	15	24	7	28	12	5	4	5	27	9	6	57	6
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

Table B6 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.5	-4.6	3.7	3.5	-4.5	-4.3	4	3.5	-4.6	-4.1	3.8	3.1	-4.6	-4.4	3.7	3.4	-4.6	-4.4	3.8	2.6	-4.6	-4.3	3.9	3.1	3.8
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
>4.0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
>3.0	1	2	1	1	5	1	0	2	3	3	0	2	5	1	0	0	4	2	0	0	1	5	0	0	69
>2.0	645	589	299	264	488	556	118	553	486	577	473	480	501	824	456	456	572	511	403	694	493	561	487	401	24064
>1.0	1578	1125	547	566	1196	1362	322	943	1079	1243	876	1233	1190	1307	901	931	1012	1144	942	1548	1265	1381	757	1303	53146
>0.0	58	78	22	24	76	26	4	64	80	73	24	14	43	61	53	10	65	61	44	45	63	21	105	15	2361
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																								
>8.0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	8
>7.0	0	1	0	4	17	0	2	5	0	0	0	4	0	0	5	0	1	3	3	0	0	0	0	0	94
>6.0	64	150	530	558	341	229	461	550	216	122	577	493	331	205	558	519	238	145	581	422	235	179	607	614	16809
>5.0	343	311	1473	1424	497	512	1277	1560	461	459	1150	1530	549	460	1137	1574	542	402	1156	1573	442	529	1270	1386	44912
>4.0	8	23	41	17	6	14	25	20	18	23	33	14	3	10	24	42	11	6	30	57	6	30	27	87	999
>3.0	0	0	0	0	0	0	2	0	0	0	5	0	0	0	0	0	0	0	0	2	0	0	7	7	24
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table B7
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for State Underkeel Clearance Criteria for 43-ft Vessel Draft, 49-ft Entrance-Channel Depth, 45-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-4.6	-4.5	3.6	4.1	-4.1	-4.7	3.4	4.1	-4.4	-4.6	3.6	3.8	-4.1	-4.6	3.9	4.4	-4.3	-4.7	3.9	4.3	-4.5	-4.6	3.9	4.2
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	57	73	17	19	58	125	32	54	135	91	48	22	62	69	83	17	115	82	42	9	70	69	51	12
>2.0	1845	1997	707	1256	2096	1816	853	1858	1737	2061	924	1752	1842	1985	1336	1728	1864	2088	1313	1632	1848	2132	956	1754
>1.0	129	215	83	217	115	205	65	289	166	90	170	262	194	238	226	196	167	211	134	215	176	213	139	151
>0.0	0	1	0	0	3	0	0	0	0	0	1	0	0	0	1	3	2	0	0	0	6	1	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																							
>8.0	0	0	3	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	8	7	14	50	6	24	35	36	1	8	65	31	5	5	65	11	10	8	60	53	9	11	128	87
>6.0	390	665	1885	1786	473	745	1884	1511	521	927	1796	1835	608	677	1874	1774	496	858	1898	1829	497	980	1843	1590
>5.0	43	110	188	152	51	45	188	90	59	90	208	172	84	80	252	140	64	94	270	146	67	85	362	261
>4.0	0	0	1	3	0	1	0	0	0	0	4	0	1	0	0	1	0	0	0	13	0	0	7	6
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

Table B7 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.2	-4.1	4.1	4.3	-4.2	-4.2	4.3	4.3	-4.4	-4.3	4.3	4.4	-4.5	-4.3	4.2	4.2	-4.2	-4.6	3.6	4.3	-4.1	-4.4	4	4.3	4.07
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	3	0	0	1	0	0	0	7
>3.0	159	74	0	42	73	73	50	50	142	109	31	42	122	77	49	72	140	68	52	70	64	87	46	31	3135
>2.0	1888	2087	577	1241	1942	1933	1137	1137	1980	2037	1196	2143	1939	1993	1339	2019	1968	1882	1255	1236	1857	1988	1594	1297	79045
>1.0	296	253	59	99	155	184	161	161	282	160	97	256	217	190	235	331	282	253	195	400	250	289	368	249	9688
>0.0	8	0	0	0	0	0	0	0	9	2	0	0	3	0	2	0	14	2	0	0	0	1	5	0	64
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																								
>8.0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	10
>7.0	6	5	85	57	8	22	46	47	14	25	49	48	8	14	25	56	9	9	98	82	15	16	74	71	1626
>6.0	509	662	2021	1498	562	1148	1650	1647	513	1098	1667	1487	578	615	1646	1459	472	706	1894	1719	891	780	1536	1696	57796
>5.0	98	42	327	318	58	75	177	179	78	46	158	127	49	84	65	188	108	107	274	187	80	67	142	282	6617
>4.0	0	0	0	0	0	0	2	2	1	0	0	1	0	0	0	0	1	0	4	2	0	2	0	0	52
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table B8
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat for State HDOT Underkeel Clearance Criteria for 43-ft Vessel Draft, 49-ft Entrance-Channel Depth, 45-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-4.2	-4.3	4.1	3.4	-4.5	-4.5	4.1	3.8	-4.3	-4.5	3.5	3.8	-4.4	-4.6	3.6	3.7	-4.3	-4.4	3.9	3.9	-4.5	-4.7	3.9	4
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	73	53	13	145	134	93	47	47	91	94	9	48	74	74	186	18	66	71	71	25	134	93	51	83
>2.0	1648	1563	781	1020	1371	1907	1135	1094	1495	1891	644	919	1427	1279	821	1069	1442	1250	1007	885	1404	1298	1258	715
>1.0	283	295	110	244	310	268	199	160	283	309	156	194	250	184	300	253	310	169	178	291	302	280	212	95
>0.0	0	12	0	0	5	2	0	2	6	2	0	8	3	0	2	3	8	0	0	0	1	0	0	4
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																							
>8.0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2	0	0	0	0
>7.0	8	11	104	65	4	9	105	183	7	15	22	70	3	21	163	58	0	13	66	43	2	22	101	114
>6.0	509	518	1774	1483	262	543	1539	1569	479	655	1601	1788	306	624	1582	1127	407	487	1743	1227	370	357	1612	1010
>5.0	105	95	220	390	32	67	232	319	81	51	133	248	61	68	373	293	71	68	207	158	67	74	274	157
>4.0	0	0	19	4	0	0	9	7	0	0	6	2	0	0	8	11	0	0	3	0	0	0	2	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

Table B8 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.6	-4.8	3.8	3.8	-4.5	-4.6	4.1	4	-4.5	-4	3.9	4.1	-4.4	-4.3	4.3	3.7	-4.6	-4.6	4	4	-4.4	-4.4	4	4.2	4.03
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
>4.0	1	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	17
>3.0	142	84	44	36	88	159	21	57	76	38	21	72	195	74	14	25	63	66	43	18	74	125	55	73	3456
>2.0	1364	1368	1388	950	1570	1258	750	409	1611	1042	1028	730	1373	1611	471	1274	1719	1811	1012	1003	1540	1673	1196	1752	59226
>1.0	319	241	350	220	286	241	105	163	331	245	97	219	377	222	166	191	252	244	124	214	208	380	231	358	11419
>0.0	6	2	0	2	3	0	0	7	4	7	0	5	6	2	1	3	1	1	0	0	6	1	0	1	116
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in each Depth Bin over the Entrance Channel																								
>8.0	0	0	0	0	0	0	5	1	0	0	2	0	0	0	1	0	0	7	0	0	0	0	0	0	20
>7.0	5	13	40	85	7	21	135	73	26	22	103	99	8	17	88	29	15	30	104	92	2	17	51	55	2346
>6.0	577	502	1737	1226	596	644	1692	953	513	431	1796	1103	415	674	1467	1269	465	665	1682	1683	437	594	1495	1185	47373
>5.0	70	67	205	162	57	72	295	130	80	102	250	97	131	151	286	269	79	83	185	318	136	87	231	185	7572
>4.0	0	0	0	0	0	0	9	4	0	0	0	0	0	0	14	0	0	0	11	11	0	0	2	0	122
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix C
U.S. Army Engineer Division, Pacific Ocean (POD), Underkeel Clearance Criteria Results for the APL C9-Class Containership

See Appendix A for description of tables.

Table C1
Number of Occurrences of Keel Motion Through Different Depth Bins for APL C9-Class Containership for Corps POD Underkeel Clearance Criteria for 35-ft Vessel Draft, 43-ft Entrance-Channel Depth, 39-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-4.4	-4.6	4.3	4.2	-5.4	-4.8	4.3	4.2	-5.1	-4.8	4.3	5.4	-5.2	-4.7	4.4	4.7	-5.2	-4.9	4.1	4.1	-5.3	-5	4.6	4
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	1	4	0	0	0	0
>5.0	1	4	16	31	8	6	14	3	2	5	15	13	2	1	13	33	1	21	28	39	10	5	27	20
>4.0	758	748	647	561	638	810	371	361	690	844	603	408	696	738	341	302	728	762	522	529	685	734	377	308
>3.0	784	879	372	506	592	739	432	495	703	762	359	273	672	794	269	461	651	701	446	403	641	760	409	536
>2.0	30	1	4	0	31	12	5	0	22	23	4	1	19	13	0	0	37	9	7	0	36	14	0	3
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																							
>8.0	527	471	674	776	383	493	653	850	447	411	627	717	475	451	676	779	422	482	735	693	389	416	796	736
>7.0	298	308	728	684	247	324	642	617	307	351	723	496	245	316	648	655	267	260	633	720	303	332	630	657
>6.0	3	1	3	14	0	0	0	18	2	0	3	5	1	1	4	0	3	1	16	22	1	0	4	6
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

Table C1 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.7	-4.9	4.6	4	-5.1	-4.8	4.3	3.7	-5.1	-4.8	4.2	4.1	-5	-4.8	4.9	4.2	-5.3	-4.7	4.6	3.9	-5.1	-4.4	4.7	4	4.4565705
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	1	0	0	4	4	0	0	0	0	0	0	0	1	0	0	0	1	20
>5.0	3	1	0	21	19	10	2	13	7	4	6	17	0	3	8	20	15	6	15	14	8	3	0	36	549
>4.0	797	762	248	488	764	794	212	388	691	708	377	277	727	711	332	394	728	690	347	344	713	752	344	309	27058
>3.0	738	769	362	506	747	736	317	397	717	673	232	259	720	648	391	451	740	595	325	479	764	705	389	412	26711
>2.0	15	15	5	10	23	20	0	3	43	23	0	2	10	17	0	1	21	22	0	0	20	14	2	7	544
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																								
>8.0	469	423	762	914	368	437	682	773	408	438	872	697	460	437	743	774	330	332	699	762	404	483	805	648	28199
>7.0	330	327	598	573	236	359	754	640	274	253	585	691	249	336	593	655	210	330	718	686	346	329	558	803	22824
>6.0	0	0	26	2	0	0	15	2	2	0	3	11	0	0	9	28	3	2	3	0	6	0	14	4	238
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table C2
Number of Occurrences of Keel Motion Through Different Depth Bins for APL C9-Class Containership for Corps POD Underkeel Clearance Criteria for 35-ft Vessel Draft, 43-ft Entrance-Channel Depth, 39-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1i3	1i4	1u1	1u2	1u3	2i1	2i2	2i3	2u1	2u2	2u3	3i1	3i2	3i3	3u1	3u2	3u2	4i1	4i2	4i3	4u1	4u2	4u3	5i1	5i2	5i3	5u1	5u2	5u3	6i1	6i2	6i3	6u1	6u2	6u3
Vessel speed, knots	-5.4	-4.9	-4.7	-4.7	4.2	4.2	3.8	-5	-4.8	-4.8	3.7	4.2	4.4	-4.7	-4.8	-4.9	4	3.7	4.2	-4.8	-5.1	-4.9	4	3.9	4.1	-4.7	-4.9	-4.7	4.2	4	4.2	-5	-4.5	-4.9	4	4.3	4.1
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																																				
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	4	2	0	0	0	0	2	1	0	0	21	0	1	1	0	0	2	1	1	2	0	1	4	0	7	4	0	8	0	0	2	10	0	0	1
>4.0	0	678	795	779	5	301	464	61	745	775	9	307	571	44	714	737	2	426	364	31	597	728	1	578	340	21	671	736	2	317	257	49	782	691	17	362	341
>3.0	0	391	516	529	20	419	501	65	420	534	5	411	425	58	508	567	1	513	406	60	446	553	10	629	436	32	518	675	12	544	496	57	486	658	31	420	470
>2.0	0	19	21	24	0	0	0	0	9	18	0	0	4	0	17	12	0	0	0	0	16	15	0	0	0	0	19	18	0	19	0	0	22	15	0	2	3
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																																				
>8.0	0	411	400	431	12	742	733	0	349	429	2	782	749	1	418	423	8	775	823	0	403	414	5	672	805	0	395	478	10	800	843	0	446	466	3	689	826
>7.0	0	528	600	508	4	637	638	0	582	510	6	610	634	3	518	487	9	649	591	0	509	496	11	659	630	0	481	481	10	579	651	1	578	496	3	662	603
>6.0	0	0	0	2	0	3	0	0	0	0	0	2	4	0	0	0	0	5	19	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	1	42
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

Table C2 (Concluded)

Code	7i1	7i2	7i3	7u1	7u2	7u3	8i1	8i2	8i3	8u1	8u2	8u3	9i1	9i2	9i3	9u1	9u2	9u3	ai1	ai2	ai3	au1	au2	au3	bi1	bi2	bi3	bu1	bu2	bu3	ci1	ci2	ci3	cu1	cu2	cu3	Average
Vessel speed, knots	-4.6	-5	-4.9	4.1	4	4.6	-5	-5	-5.2	3.5	4.1	4.2	-4.5	-4.7	-4.9	3.8	4	4.6	-4.4	-4.9	-4.5	3.8	3.7	3.8	-5	-4.6	-4.4	4.1	4.2	4.1	-5	-4.8	-4.5	3.8	4.3	3.9	4.43
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																																				Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
>5.0	0	2	4	0	7	0	0	0	5	0	0	1	1	7	1	0	0	21	0	4	4	0	15	54	0	0	8	0	0	12	0	8	0	0	0	0	229
>4.0	48	643	717	6	339	288	51	630	725	2	322	281	41	713	750	6	406	359	57	632	750	6	298	466	27	640	683	5	432	533	65	628	678	11	383	455	27374
>3.0	83	439	534	6	570	508	62	580	624	2	591	434	75	433	631	14	533	218	48	556	692	18	653	529	101	548	682	24	458	513	64	485	807	9	461	688	26495
>2.0	0	19	21	0	7	0	0	14	20	0	0	1	0	21	24	0	1	0	0	35	31	0	2	9	0	22	23	0	1	9	0	16	25	0	1	1	556
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																																				
>8.0	1	421	405	2	785	766	0	408	492	1	827	822	1	408	471	4	766	694	0	459	440	3	865	694	0	477	593	18	775	879	0	428	599	4	736	902	29889
>7.0	1	508	484	10	623	601	0	484	337	10	552	600	0	533	385	1	583	577	0	461	354	4	599	626	0	456	335	27	571	648	0	515	352	5	606	622	26834
>6.0	0	0	2	0	1	8	0	0	0	0	16	9	0	0	2	0	39	0	0	1	4	0	8	1	0	0	0	0	7	1	0	0	4	0	9	6	199
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix D
Hawaii Department of Transportation (HDOT) Underkeel Clearance Criteria Results for the APL C9-Class Containership

See Appendix A for description of tables.

Table D1
Number of Occurrences of Keel Motion Through Different Depth Bins for APL C9-Class Containership for State HDOT Underkeel Clearance Criteria for 35-ft Vessel Draft, 41-ft Entrance-Channel Depth, 37-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-4.7	-4.6	4.1	3.9	-4.7	-4.6	4.8	3.8	-5	-4.5	4.4	4.1	-4.7	-4.6	4.5	4.2	-5.2	-4.5	4.4	4	-5	-4.8	4.4	4.4
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	1	0	2	1	15	0	0	0	2	4	8	0	0	5	0	0	4	2	2	5	9	1	1	0
>2.0	749	802	618	726	783	952	496	683	781	843	557	743	724	898	463	729	751	889	581	746	756	1002	532	690
>1.0	782	824	596	733	751	718	571	709	614	856	575	785	818	895	666	736	633	933	477	853	695	638	661	725
>0.0	6	13	2	0	32	19	0	0	20	6	1	0	9	21	5	1	31	7	7	5	24	25	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0
>7.0	4	0	4	0	3	0	0	2	4	0	0	0	2	0	5	0	0	5	0	0	6	3	0	1
>6.0	470	442	751	804	469	370	707	734	396	478	792	712	463	428	848	831	340	475	707	857	439	318	817	843
>5.0	349	436	731	703	349	495	569	675	385	418	584	794	362	473	537	678	372	413	717	658	331	470	587	649
>4.0	0	0	0	0	0	0	2	1	0	0	19	2	0	0	8	21	0	0	0	0	0	0	3	8
>3.0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(Continued)

Table D1 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-5.1	-4.7	4.3	4.7	-4.8	-4.7	4.8	4.9	-5	-4.7	4.8	4.5	-5	-4.4	4.4	4.6	-5	-5.2	4.9	3.9	-4.7	-4.5	4.2	4	4.41
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	5	3	7	0	7	4	3	3	6	2	6	0	2	1	6	0	0	1	0	3	3	1	0	1	126
>2.0	748	904	600	487	753	783	540	503	749	939	502	576	734	780	570	542	738	748	469	666	797	191	554	407	32774
>1.0	709	834	496	568	759	841	486	526	670	758	475	676	795	916	622	627	732	703	584	722	751	175	616	401	32686
>0.0	6	27	3	4	24	12	30	0	9	17	1	1	9	6	0	0	12	25	2	3	10	2	0	0	437
Bottom	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																								
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
>7.0	3	3	1	0	7	0	0	0	4	0	8	0	11	7	1	4	8	0	0	1	11	0	0	1	109
>6.0	388	393	752	813	464	469	729	806	424	342	661	753	475	522	794	800	425	341	678	844	522	193	794	824	28697
>5.0	369	410	621	574	308	386	554	510	346	481	591	681	317	413	557	584	370	405	578	755	317	320	710	800	24692
>4.0	0	0	2	23	1	0	20	23	0	0	5	1	0	0	2	15	0	0	13	18	0	0	6	5	198
>3.0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	8
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table D2
Number of Occurrences of Keel Motion Through Different Depth Bins for APL C9-Class Containership for State HDOT Underkeel Clearance Criteria for 35-ft Vessel Draft, 41-ft Entrance-Channel Depth, 37-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 4-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3i2	3u1	3u2	4i1	4i2	4u1	4u2	5i1	5i2	5u1	5u2	6i1	6i2	6u1	6u2
Vessel speed, knots	-4.1	-5	4.1	4.2	-4.7	-4.5	3.8	4.5	-4.9	-5.2	4.2	4.5	-5	-5.2	4.5	4.8		-5	4.1	4.4	-4.8	-5.3	4.3	4.8
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>3.0	1	1	0	0	0	0	0	0	0	5	3	0	0	5	2	0		3	0	1	8	0	0	1
>2.0	661	799	498	338	649	736	477	401	297	794	367	445	274	719	373	350		808	549	440	889	766	536	386
>1.0	553	531	499	478	448	562	539	505	184	480	342	447	161	550	383	547		480	661	528	574	532	507	610
>0.0	4	16	0	3	17	12	0	0	2	17	3	0	0	11	3	1		13	0	0	10	5	8	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																							
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>7.0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	2	0		0	0	0	0	0	0	15
>6.0	439	371	797	800	402	359	715	692	236	393	795	687	258	425	683	672		354	714	665	419	357	702	623
>5.0	557	477	634	567	462	513	684	583	348	475	538	551	258	410	662	471		506	671	499	553	451	651	467
>4.0	0	0	4	15	0	0	0	15	0	0	23	26	0	0	3	22		0	0	0	0	0	4	2
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0

(Continued)

Table D2 (Concluded)

Code	7i1	7i2	7u1	7u2	8i1	8i2	8u1	8u2	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-5.1	-5.4	4.3	3.9	-4.8	-4.5	4.5	4.7	-4.7	-5.4	4.1	5	-4.5	-4.2	4.3	4.4	-5	-4.4	4.1	4.4	-4.8	-4.6	4.7	4.1	4.43
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																								Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	3	1	1	0	5	0	1	40	2	2	0	1	2	2	0	0	7	6	0	0	2	12	3	3	123
>2.0	772	691	557	422	701	0	557	411	789	644	525	415	891	876	642	552	794	809	622	539	782	816	486	501	27346
>1.0	574	590	577	668	649	0	630	488	657	656	646	468	678	703	531	463	580	658	568	485	550	587	617	504	24628
>0.0	11	13	0	1	8	0	0	40	8	23	0	1	13	11	0	1	12	15	0	1	11	12	2	0	308
Bottom	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																								
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
>7.0	0	6	0	5	0	0	1	1	0	3	0	0	0	5	0	0	0	4	0	3	0	0	11	0	64
>6.0	414	430	664	752	431	0	633	706	423	458	747	624	439	496	704	658	356	517	745	745	370	399	652	752	25673
>5.0	453	330	682	640	474	0	673	429	518	314	646	513	573	472	654	534	542	372	645	555	486	532	555	584	24164
>4.0	0	0	3	7	0	0	1	27	0	2	3	1	2	3	0	0	0	2	0	0	5	0	6	5	181
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix E Results for the Modified Bunga Saga Empat Bulk-Cargo Carrier with Modified Transition Difference and Location

See Appendix A for description of tables.

Table E1

Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 41-ft Vessel Draft, 47-ft Entrance-Channel Depth, 45-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 2-ft Transition at Proposed Location

Code	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-5	-4	4.3	4	-5	-5		4.2	-5	-5	4	4	-4	-5	4	4	4.41
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																Total
>8.0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	4	0	0		0	0	0	2	1	0	0	0	0	7
>4.0	1	7	15	23	0	0		108	8	0	76	69	5	7	47	21	387
>3.0	8	19	32	30	21	6		27	4	9	11	47	12	17	49	36	328
>2.0	0	0	1	0	0	0		0	0	0	0	6	0	0	0	0	7
>1.0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0.	0
>0.0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each depth Bin over the Entrance Channel																
>8.0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0		0	0	0	1	1	0	0	0	0	2
>6.0	5	7	15	11	0	0		23	0	0	18	50	3	2	10	7	151
>5.0	4	3	12	28	0	0		25	0	0	20	51	4	17	17	19	200
>4.0	0	0	0	0	0	0		0	0	0	0	0	0	2	0	1	3
>3.0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0

Table E2
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 41-ft Vessel Draft, 46-ft Entrance-Channel Depth, 44-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 2-ft Transition at Proposed Location

Code	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.4	-4.4	3.8	4.5	-4.4	-4.4	3.5	4	-4.3	-4.7	4.1	4.2	-4.6	-4.4	4.1	3.9	4.23
Depth bins, ft	Number of Occurrence in Each Depth Bin over the Harbor																Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	2
>3.0	3	3	18	18	1	5	23	75	2	3	40	20	5	0	41	33	290
>2.0	6	12	81	74	11	10	110	52	25	24	32	88	4	3	54	72	658
>1.0	0	0	15	1	0	0	5	8	0	0	3	8	0	0	3	3	46
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrence in Each Depth Bin over the Entrance Channel																
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	3
>5.0	1	4	0	6	0	2	3	25	0	8	3	1	8	1	3	1	66
>4.0	5	9	7	15	3	4	3	17	0	7	17	2	4	2	15	14	124
>3.0	0	2	2	0	0	0	0	0	0	0	1	0	0	0	0	0	5
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E3
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 41-ft Vessel Draft, 45-ft Entrance-Channel Depth, 43-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 2-ft Transition at Proposed Location

Code	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.2	-3.7	2.8	3.3	-3.9	-3.8	2.8	2.8	-3.9	-4	2.4	2.5	-3.9	-3.9	2.7	2.8	3.34
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	0	0	0	0	0	1	2	0	0	0	2	0	0	0	0	0	5
>2.0	5	4	72	3	11	6	64	58	0	10	22	80	20	5	121	44	525
>1.0	19	26	187	14	34	50	192	155	45	14	87	202	22	40	40	127	1254
>0.0	0	0	7	3	0	2	21	6	0	0	1	14	0	0	0	9	63
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	7	1	4	2	15	14	8	0	4	10	3	13	20	0	4	5	110
>3.0	27	6	30	11	9	20	28	3	2	8	14	30	28	16	15	22	269
>2.0	2	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	6
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E4
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 41-ft Vessel Draft, 47-ft Entrance-Channel Depth, 45-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 2-ft Transition at Proposed Location

Code	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, Knots	-4.1	-4.4	4.2	4.1	-4	-4.3	3.8	3.5	-4.3	-4.7	4.1	4.2	-4.4	-4.4	3.9	4.2	4.2
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	1	1	4	0	0	2	1	0	0	2	2	0	11	1	11	36
>4.0	42	706	48	342	104	491	143	717	57	648	153	583	737	632	724	489	6616
>3.0	288	1585	239	910	360	1701	343	1602	249	1394	350	1248	1663	1558	1623	1261	16374
>2.0	3	10	2	25	4	32	37	34	36	51	10	29	5	48	39	87	452
>1.0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	12
>7.0	1	4	0	9	8	0	0	0	0	0	0	1	0	0	3	33	59
>6.0	119	343	36	716	84	399	51	777	52	335	65	571	287	282	595	777	5489
>5.0	419	950	156	1693	289	814	126	1684	297	790	172	1572	847	839	1337	1358	13343
>4.0	4	6	4	39	6	4	6	45	30	12	4	32	13	8	31	31	275
>3.0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	11
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E5
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 41-ft Vessel Draft, 46-ft Entrance-Channel Depth, 44-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 2-ft Transition at Proposed Location

Code	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, Knots	-4.6	-4.5	4.4	4.2	-4.4	-4.7	4.4	4.5	-4.7	-4.8	4.5	4.2	-4.6	-4.6	4.3	4.5	4.5
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	5	0	1	2	26	1	4	10	3	1	2	0	12	67
>3.0	508	544	358	437	603	578	530	485	432	707	608	545	474	639	473	419	8340
>2.0	1418	1613	1007	1083	1471	1365	1320	909	1515	1097	1375	1471	1551	1430	1206	1097	20928
>1.0	59	70	34	25	43	73	61	18	68	105	83	69	39	32	10	26	815
>0.0	1	0	0	0	0	0	0	0	0	5	0	1	0	0	0	0	7
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4
>6.0	0	0	0	1	0	0	10	1	0	9	0	0	0	0	40	2	63
>5.0	317	244	624	647	252	151	723	634	282	199	665	633	141	204	559	812	7087
>4.0	780	679	1600	1604	667	635	1298	1584	773	543	1244	1506	723	586	1571	1395	17188
>3.0	7	18	19	77	6	4	78	27	1	17	41	53	2	13	49	62	474
>2.0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E6
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 41-ft Vessel Draft, 45-ft Entrance-Channel Depth, 43-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 2-ft Transition at Proposed Location

Code	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.4	-4.1	3.6	3.1	-4	-4.1	3.3	2.8	-4.3	-4.4	3.1	3	-4.4	-4.2	3.4	2.4	3.7
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	5	0	0	0	10	3	0	3	24	12	4	0	1	10	2	26	100
>2.0	668	701	479	247	833	687	618	655	646	567	430	520	634	837	511	696	9729
>1.0	1695	1532	1152	799	1472	1465	1406	1748	1621	1545	1589	1607	1543	1500	1418	1429	23521
>0.0	21	14	37	19	62	36	46	78	18	25	22	23	28	53	44	69	595
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	3
>6.0	0	0	0	0	0	0	2	0	0	0	2	0	0	0	2	0	6
>5.0	0	0	0	0	0	0	11	5	4	0	4	1	0	1	7	0	33
>4.0	200	248	669	651	238	290	700	560	320	258	637	471	206	426	680	664	7218
>3.0	510	639	1664	1260	716	545	1714	1659	593	493	1745	1758	552	588	1711	1466	17613
>2.0	3	13	61	15	11	1	42	5	7	13	16	0	13	11	38	15	264
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E7
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 43-ft Vessel Draft, 49-ft Entrance-Channel Depth, 47-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 2-ft Transition at Proposed Location

Code	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.8	-4.7	4.3	4.3	-4.9	-4.7	3.9	4.3	-4.8	-4.8	3.8	4.2	-4.8	-4.7	4.3	4.4	4.5
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	1	1	0	3	0	1	4	0	0	0	0	4	0	1	15
>4.0	180	206	182	225	251	282	186	123	255	250	210	204	273	214	208	163	3412
>3.0	363	399	288	178	515	599	273	278	344	822	337	237	406	265	325	245	5874
>2.0	2	8	7	4	14	26	0	2	4	11	1	3	24	5	11	3	125
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	11	14
>6.0	16	0	139	91	32	59	87	111	5	84	62	84	15	5	130	78	998
>5.0	57	11	138	236	46	102	184	140	30	174	201	171	29	14	195	147	1875
>4.0	0	0	1	2	0	0	2	3	0	0	5	3	0	0	4	0	20
>3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E8
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 43-ft Vessel Draft, 48-ft Entrance-Channel Depth, 46-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 2-ft Transition at Proposed Location

Code	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.6	-4.6	4.1	4	-4.4	-4.2	4.1	4.3	-4.7	-4.2	4.1	4	-4.6	-4.4	3.9	3.9	4.3
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	6	20	0	10	0	16	27	5	0	22	15	7	3	27	12	18	188
>2.0	10	58	10	14	0	17	23	13	0	58	0	7	15	75	12	24	336
>1.0	0	0	8	0	0	0	0	0	0	0	0	4	0	0	0	0	12
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
>5.0	5	5	1	7	0	9	22	9	0	7	4	2	9	8	8	4	100
>4.0	9	26	7	14	0	30	60	18	0	33	11	3	27	67	23	2	330
>3.0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	2
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E9
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 43-ft Vessel Draft, 49-ft Entrance-Channel Depth, 47-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 2-ft Transition at Proposed Location

Code	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.6	-4.6	3.9	4	-4.3	-4.4	3.9	4	-4.5	-4.5	3.6	4	-4.2	-4.4	4.1	3.9	4.2
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	3	3	0	4	7	4	2	2	4	12	0	0	4	43	10	2	100
>4.0	881	873	752	404	803	1099	812	515	942	785	557	364	838	927	560	409	11521
>3.0	1207	1211	1384	740	1275	1163	1009	1143	1365	122 9	709	1078	1303	1180	782	806	17584
>2.0	19	19	9	8	25	46	0	8	33	14	11	3	20	45	13	6	279
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	1	1	34	1	0	0	5	11	1	0	17	37	1	4	14	20	147
>6.0	225	216	683	935	314	543	586	915	314	484	933	795	278	421	861	1053	9556
>5.0	456	454	1346	1323	419	775	1388	1312	403	563	1228	1426	536	740	1167	1457	14993
>4.0	1	1	19	65	13	6	70	89	1	0	7	20	11	27	49	85	464
>3.0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	3
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E10
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 43-ft Vessel Draft, 48-ft Entrance-Channel Depth, 46-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 2-ft Transition at Proposed Location

Code	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.4	-4.4	4.2	3.7	-4.3	-4.1	4	3.5	-4.5	-4.4	3.9	3.9	-3.9	-4.4	3.8	3.8	4.1
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	29	5	7	15	0	5	2	15	13	3	5	5	7	0	2	2	115
>3.0	963	906	699	642	1190	809	455	805	895	807	963	762	822	944	496	496	12654
>2.0	1285	1163	1216	1090	1214	1137	878	1287	1364	1112	1314	1093	1319	1346	658	658	18134
>1.0	17	72	53	26	21	92	54	54	23	50	39	6	18	30	2	2	559
>0.0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrence in Each Depth Bin over the Entrance Channel																
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	1	3	0	0	2	12	5	0	7	5	10	2	0	10	10	67
>5.0	229	242	889	842	240	293	1096	876	227	241	734	989	248	247	820	820	9033
>4.0	352	549	992	1281	586	524	1126	1350	362	412	1389	1025	539	546	1252	1252	13537
>3.0	8	15	29	16	4	30	71	23	2	11	45	43	12	1	35	35	380
>2.0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	4	4	11
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E11
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 43-ft Vessel Draft, 47-ft Entrance-Channel Depth, 45-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 2-ft Transition at Proposed Location

Code	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.1	-4.4	3.8	3.7	-4.2	-4	4.1	3.7	-4.4	-4.2	4.1	-4.2	-4.1	-4.1		4	3.5
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
>3.0	1	35	3	5	35	1	0	0	3	19	6	15	3	13		0	139
>2.0	790	782	628	386	790	813	201	308	695	786	286	577	749	851		427	9069
>1.0	1098	1088	815	389	1177	1172	495	387	1091	989	490	657	1191	1022		697	12758
>0.0	56	40	14	9	64	23	2	0	36	13	8	25	36	49		2	377
Bottom		0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
>6.0	0	0	0	0	0	0	0	0	0	1	0	0	0	0		0	1
>5.0	0	0	2	32	2	0	19	0	2	7	4	6	0	1		3	78
>4.0	312	182	966	825	371	196	1108	853	279	169	1260	365	186	174		1004	8250
>3.0	498	443	1223	1202	585	551	1398	1399	487	330	1310	909	467	336		1271	12409
>2.0	16	13	33	41	6	7	41	11	14	8	14	11	8	2		31	256
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0

Table E12
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 39-ft Vessel Draft, 45-ft Entrance-Channel Depth, 43-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 2-ft Transition at Proposed Location

Code	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.8	-4.3	4.1	4.1	-4.3	-4.5	4.3	3.9	-4.8	-4.4	4.1	4.1	-4.4	-4.4	4.1	4.6	4.32
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	1	4
>4.0	18	9	53	38	4	10	32	25	10	1	70	19	15	3	86	42	435
>3.0	91	145	626	607	161	74	801	289	152	130	662	285	90	119	509	445	5186
>2.0	16	3	71	35	9	4	80	42	15	3	87	16	27	1	68	54	531
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	5
>6.0	18	5	46	31	3	2	45	11	9	2	27	12	7	0	39	54	311
>5.0	54	32	518	505	64	42	425	527	50	72	498	447	77	35	543	478	4367
>4.0	4	9	24	42	5	9	24	45	10	5	41	35	9	28	63	36	389
>3.0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E13
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 39-ft Vessel Draft, 44-ft Entrance-Channel Depth, 42-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 2-ft Transition at Proposed Location

Code	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.6	-4.4	4.1	4.3	-4.4	-4.6	3.9	4	-4.6	-4.6	4.4	4.2	-4.3	-4.2	3.9	4.1	4.3
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
>3.0	71	46	3	10	38	0	8	10	94	2	27	3	89	0	15	26	442
>2.0	1869	1849	173	552	1969	30	566	381	1960	76	893	189	2013	18	832	136	13506
>1.0	128	40	12	5	106	0	28	3	174	3	10	23	114	0	30	15	691
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	4	5	156	65	3	0	106	74	20	1	48	10	5	1	141	0	639
>4.0	426	311	2575	2433	458	13	2076	1756	489	14	2208	89	575	14	2426	75	15938
>3.0	13	5	179	118	9	2	148	162	8	0	75	4	24	6	153	16	922
>2.0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E14
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 39-ft Vessel Draft, a 43-ft Entrance-Channel Depth, 41-ft Harbor Depth, Waves 0-deg Orientation to Entrance Channel, 2-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2i2	2u1	2u2	3i1	3u1	4u1	Average
Vessel speed, knots	-4	-3.8	2.5		-3.9	-3.9	2	1.8	-4.1	2.3		3.05
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor											Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	1	0	0	0	0	1	0	0	0	0	4	4736
>2.0	222	202	36	24	234	336	117	121	183	115	24	28416
>1.0	1966	2190	1661	492	2078	1839	954	1433	2178	1086	701	829984
>0.0	187	155	36	17	123	103	35	111	218	106	87	103008
Bottom	1	0	0	0	1	2	0	0	1	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel											
>8.0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	1	6	19	7	16	15	25	6	9	0	0	0
>3.0	461	725	2043	745	572	659	1412	1805	481	1821	73	86432
>2.0	8	0	21	17	3	6	34	10	13	9	2	2368
>1.0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0

Table E15
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 39-ft Vessel Draft, 45-ft Entrance-Channel Depth, 43-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 2-ft Transition at Proposed Location

Code	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.8	-4.9	4.6	4.8	-4.8	-4.6	4.8	4.5	-4.8	-4.9	4.5	4.3	-4.4	-4.7	4.5	4.2	4.7
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	1	2	3	0	0	0	1	0	0	1	0	0	0	0	8
>4.0	142	231	97	42	150	138	202	93	219	143	91	51	211	153	69	107	2139
>3.0	1937	1841	1152	694	2154	1957	542	526	1740	1772	950	1192	1966	1921	876	973	22193
>2.0	190	193	132	121	234	249	83	116	202	193	129	92	198	147	169	133	2581
>1.0	0	0	0	0	10	0	14	0	1	0	0	0	1	0	0	0	26
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	1	0	0	0	0	1	1	0	0	0	22	0	0	0	0	0	25
>6.0	75	60	159	127	42	44	328	224	29	24	179	132	52	74	168	140	1857
>5.0	655	940	1907	1826	1033	848	1511	1749	733	537	1852	1988	980	1170	1990	2125	21844
>4.0	39	44	140	216	76	55	291	235	18	16	187	140	63	75	172	197	1964
>3.0	0	0	0	2	0	0	1	0	0	0	1	1	0	0	0	0	5
>2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E16
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 39-ft Vessel Draft, 44-ft Entrance-Channel Depth, 42-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 2-ft Transition at Proposed Location

Code	9i1	9i2	9u1	9u2	ai1	ai2	au1	au2	bi1	bi2	bu1	bu2	ci1	ci2	cu1	cu2	Average
Vessel speed, knots	-4.7	-4.9	4.2	4.4	-4.6	-4.5	3.9	3.8	-5	-5	4.3	4.2	-4.6	-4.5	4.4	3.9	4.4
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor																Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	1	0	0	0	2	0	0	10	0	0	0	13
>3.0	124	190	27	17	148	123	26	26	91	121	43	32	116	100	13	4	1201
>2.0	1765	1748	946	635	1859	1986	868	870	1675	1845	764	938	1751	1909	685	578	20822
>1.0	196	101	28	12	236	164	30	48	180	198	64	42	111	115	31	31	1587
>0.0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel																
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	20
>5.0	42	49	192	70	37	44	162	187	43	24	128	121	42	52	261	161	1615
>4.0	716	992	2216	2374	905	870	2218	2128	899	512	2187	2024	817	802	2159	1946	23765
>3.0	11	22	131	117	64	46	230	186	69	15	183	62	60	43	241	100	1580
>2.0	0	2	0	0	0	0	10	2	1	0	0	0	0	0	0	3	18
>1.0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E17
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 39-ft Vessel Draft, 43-ft Entrance-Channel Depth, 41-ft Harbor Depth, Waves 20-deg Orientation to Entrance Channel, 2-ft Transition at Proposed Location

Code	1i1	1i2	1u1	1u2	2i1	2u1	2u2	3i1	3u1	4i1	4u1	9u1	Average
Vessel speed, knots	-4.2	-4	2.8	2.2	-3.9	2.3	2	-4	2.2	-4	2.5	1.9	2.62
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor												Total
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.0	0	0	0	0	0	0	0	0	0	0	0	0	0
>3.0	1	0	0	1	8	0	0	0	0	1	0	0	11
>2.0	98	254	36	130	114	23	75	225	3	264	45	92	1359
>1.0	1882	2060	1171	2264	1833	877	1455	1837	767	1822	1046	1982	18996
>0.0	82	206	24	126	106	21	40	141	5	165	80	66	1062
Bottom	0	4	0	0	0	0	0	1	0	5	0	0	10
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Entrance Channel												
>8.0	0	0	0	0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0	0	0	0	0
>6.0	0	0	0	0	0	0	0	0	0	0	0	0	0
>5.0	0	0	4	0	0	0	0	0	0	0	0	0	4
>4.0	25	25	57	69	13	44	12	18	12	50	28	12	365
>3.0	949	851	2088	2220	957	2023	2444	937	2161	1185	1995	2829	20639
>2.0	56	12	82	56	56	36	18	34	34	54	58	24	520
>1.0	0	0	0	0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix F
Results for the Modified Bunga Saga Empat Bulk-Cargo Carrier in the Entrance Channel

See Appendix A for description of tables.

Table F1
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 42-ft Vessel Draft, 47-ft Entrance-Channel Depth, Waves 0-deg Orientation to Entrance Channel, Run 1 in Entrance Channel

Code	9i1	9u1	ai1	au1	bi1	bu1	ci1	cu1	Total
Vessel speed, knots	-4.2	4.1	-4.4	4	-4.3	4.1	-4.4	3.9	-1.2
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor								
>8.0	2	0	0	0	0	0	0	0	2
>7.0	0	0	0	0	2	0	0	0	2
>6.0	1	0	18	12	46	0	44	34	155
>5.0	1572	1640	1855	1369	1931	0	1568	1252	11187
>4.0	1637	1594	1846	1396	1961	0	1300	1462	11196
>3.0	19	0	25	1	20	0	198	41	304
>2.0	0	0	0	0	0	0	1	0	1
>1.0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0

Table F2
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 42-ft Vessel Draft, 47-ft Entrance-Channel Depth, Waves 0-deg Orientation to Entrance Channel, Run 2 in Entrance Channel

Code	9i2	9u2	ai2	au2	bi2	bu2	ci2	cu2	Total
Vessel speed, knots	-4.3	3.8	-4.6	4.2	-4.2	3.9	-4.4	4.2	
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor								
>8.0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	2	0	0	0	2
>6.0	2	0	14	0	7	2	44	3	72
>5.0	1742	981	1260	174	1481	144	1568	172	7522
>4.0	1918	686	1284	114	1617	286	1300	177	7382
>3.0	16	0	44	0	26	0	198	26	310
>2.0	0	0	2	0	0	0	1	0	3
>1.0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0

Table F3
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 42-ft Vessel Draft, 47-ft Entrance-Channel Depth, Waves 0-deg Orientation to Entrance Channel, Run 3 in Entrance Channel

Code	9i3	9u3	ai3	au3	bi3	bu3	ci3	cu3	Total
Vessel speed, knots	-4.6	3.9	-4.6	4	-4.4	4.5	4.3	4.2	
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor								
>8.0	0	0	0	0	0	0	0	0	0
>7.0	0	0	2	0	0	0	0	0	2
>6.0	0	0	14	0	20	0	86	37	157
>5.0	1587	232	1560	357	1600	372	1155	445	7308
>4.0	1382	338	1459	522	1706	474	1303	333	7517
>3.0	12	0	96	3	4	12	48	24	199
>2.0	0	0	16	0	0	0	0	1	17
>1.0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0

Table F4
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 42-ft Vessel Draft, 47-ft Entrance-Channel Depth, Waves 0-deg Orientation to Entrance Channel, Run 4 in Entrance Channel

Code	9i4	9u4	ai4	au4	bi4	bu4	ci4	cu4	Total
Vessel speed, knots	-4	4	-4	4	-4.5	3.7	-4.3	4.1	
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor								
>8.0	0	0	0	0	0	0	1	0	1
>7.0	0	0	0	0	0	0	2	0	2
>6.0	1	0	17	0	5	1	97	1	122
>5.0	1969	179	1751	120	1646	295	1621	133	7714
>4.0	1864	379	1846	303	1739	241	1733	377	8482
>3.0	0	0	13	0	3	0	55	5	76
>2.0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0

Table F5
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 42-ft Vessel Draft, 47-ft Entrance-Channel Depth, Waves 0-deg Orientation to Entrance Channel, Run 5 in Entrance Channel

Code	9i5	9u5	ai5	au5	bi5	bu5	ci5	cu5	Total
Vessel speed, knots	-4.1	3.9	-4.1	3.6	-4	3.9	-4.2	3.8	
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor								
>8.0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0
>6.0	4	0	38	0	6	0	36	5	89
>5.0	1510	69	1613	108	1539	63	1413	45	6360
>4.0	1668	111	1997	192	1559	141	1458	32	7158
>3.0	36	0	3	0	17	0	24	2	82
>2.0	1	0	0	0	0	0	0	0	1
>1.0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0

Table F6
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 42-ft Vessel Draft, 47-ft Entrance-Channel Depth, Waves 0-deg Orientation to Entrance Channel, Run 6 in Entrance Channel

Code	9i6	9u6	ai6	au6	bi6	bu6	ci6	cu6	Total
Vessel speed, knots	-4.2	3.9	-3.9	3.9	-4.2	3.7	-4.1	4.1	
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor								
>8.0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	1	0	1
>6.0	1	0	4	0	18	0	59	5	87
>5.0	1148	19	1426	44	1638	56	1549	104	5984
>4.0	1066	50	1473	49	1665	67	1517	38	5925
>3.0	0	0	5	0	36	0	27	0	68
>2.0	0	0	0	0	0	0	0	0	0
>1.0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0

Table F7
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 42-ft Vessel Draft, 47-ft Entrance-Channel Depth, Waves 0-deg Orientation to Entrance Channel, Run 7 in Entrance Channel

Code	9i7	9u7	ai7	au7	bi7	bu7	ci7	cu7	Total
Vessel speed, knots	-4.1	3.9	-4.1	3.8	-3.9	4	-3.9	4	
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor								
>8.0	0	0	0	0	0	0	0	0	0
>7.0	0	0	0	0	0	0	0	0	0
>6.0	0	0	24	0	44	10	15	0	93
>5.0	1469	19	1236	35	1349	79	1443	8	5638
>4.0	1339	53	1273	55	1300	49	1615	25	5709
>3.0	45	0	10	0	76	0	38	0	169
>2.0	0	0	2	0	0	0	0	0	2
>1.0	0	0	5	0	0	0	0	0	5
>0.0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0

Table F8
Number of Occurrences of Keel Motion Through Different Depth Bins for Modified Bunga Saga Empat, 42-ft Vessel Draft, 47-ft Entrance-Channel Depth, Waves 0-deg Orientation to Entrance Channel, Run 8 in Entrance Channel

Code	9i8	9u8	ai8	au8	bi8	bu8	ci8	cu8	Total
Vessel speed, knots	-3.9	3.6	-4.1	3.8	-4	4.1	-4.2	4.1	
Depth bins, ft	Number of Occurrences in Each Depth Bin over the Harbor								
>8.0	0	0	0	0	5	0	0	0	5
>7.0	0	0	0	0	1	0	0	0	1
>6.0	1	0	0	0	44	0	47	0	92
>5.0	1414	27	1192	35	937	4	1122	9	4740
>4.0	1586	111	1187	55	961	137	1041	42	5120
>3.0	7	0	0	0	56	0	33	0	96
>2.0	1	0	0	0	0	0	0	0	1
>1.0	0	0	0	0	0	0	0	0	0
>0.0	0	0	0	0	0	0	0	0	0
Bottom	0	0	0	0	0	0	0	0	0

Appendix G Plan 4c Impact on Barge Basin Wave Climate[1]

Harbor Description

The harbor complex presently consists of an entrance channel, deep-draft harbor, barge basin, and a resort marina. The entrance channel is 140 m (450 ft) wide, 945 m (3,100 ft) long, and 12.8 m (42 ft) deep. The deep-draft harbor basin is 11.6 m (38 ft) deep. The barge basin, located just seaward of the harbor on the south side of the entrance channel, is relatively exposed to incident wave energy. It is 67 m (220 ft) wide, 396 m (1,300 ft) long, and 7.0 m (23 ft) deep. The entrance channel is aligned approximately with the 225-deg azimuth (from SW to NE orientation). The existing harbor configuration is designated as Plan 1a, as in previous studies (e.g., Briggs et al. 1994[2]).

Planned modifications to Barbers Point Harbor include a deeper entrance channel and a rubble-mound jetty on the north side of the entrance (Plan 4c). The modifications will impact wave and swell conditions in the relatively exposed barge basin. The Pacific Ocean Division requested the U.S. Army Engineer Waterways Experiment Station (WES) to assess the impact of Plan 4c on barge basin wave climate. WES used wave climate data from the offshore S_{xy} array gauge and the numerical model HARBD to assess overall barge basin wave climate in both the existing and Plan 4c harbors. Results from previous physical model storm wave simulations were also reviewed to assess barge basin response to storms.

The proposed Plan 4c includes the following: (a) flare of the outer 305 m (1,000 ft) of the entrance channel from a width of 140 m (450 ft) to 229 m (750 ft), (b) 140-m- (450-ft-) long shore-connected rubble-mound jetty on the

[1] Appendix G was prepared by Dr. Edward F. Thompson and Messrs. Michael J. Briggs and Doyle L. Jones.

[2] Briggs, M., Lillycrop, L., Harkins, G., Thompson, E., and Green, D. (1994). "Physical and numerical model studies of Barbers Point Harbor," Technical Report CERC-94-14, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

north side of the entrance channel, (c) channel and harbor deepened to 14.9 m (49 ft) and 13.7 m (45 ft), respectively, and (d) 335-m (1,100-ft) by 335-m (1,100-ft) harbor expansion.

Incident Wave Climate

Barbers Point Harbor is subject to waves approaching the Hawaiian Islands from the northwest and the southwest. Deepwater wave approach from the west occurs rarely during Kona (local) storms. The island of Oahu shelters the harbor from waves generated by easterly trade winds. The largest waves, occurring during winter months, are swell because of storms in the northwest Pacific. Most waves measured at the S_{xy} gauge location outside the harbor complex have peak periods between 9 and 15 sec with significant wave heights ranging from 0.3 m (1 ft) to 0.9 m (3 ft).

Wave parameters for analysis from the S_{xy} gauge data were obtained from the Scripps Institution of Oceanography. Data covered the period September 1986 to October 1989. Parameters were used to develop percent occurrence tables of significant wave height, peak wave period, and dominant wave direction. Wave height intervals are 0.2 m, and wave-direction intervals are 10 deg.

Wave Climate in Barge Basin

The numerical model HARBD was used to calculate wave transformation between incident waves (S_{xy} gauge location) and waves in the barge basin for both the existing harbor and Plan 4c. Model grids used in previous long wave studies (e.g., Briggs et al. 1994[1]) were adapted for this wave and swell application. Wave periods from 9 to 20 sec, in 1-sec intervals, and wave directions from 190- to 280-deg azimuth, in 10-deg intervals, were run in the model.

HARBD results were further processed to provide directional spectral estimates of wave transformation at selected points around the harbor. The procedure is described by Thompson et al. (1996).[2] Transformation cases were matched to wave period and direction intervals used for the wave gauge climate summaries.

Wave climate percent occurrence tables from the S_{xy} gauge were then transformed into percent occurrence tables at two points along the approach to

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[1] Briggs, M., Lillycrop, L., Harkins, G., Thompson, E., and Green, D. (1994). "Physical and numerical model studies of Barbers Point Harbor," Technical Report CERC-94-14, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

[2] Thompson, E., Hadley, L., Brandon, W., McGehee, D., and Hubertz, J. (1996). "Wave response of Kahului Harbor, Maui, Hawaii," Technical Report CERC-96-11, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

the harbor (channel center about 500 ft seaward of the jetty tip and channel center at the beginning of the confined channel in line with the landward jetty end) and three points in the barge basin (north part of the barge basin and the east and south barge basin corners; Figure G1). Numerical model output station numbers are also shown in Figure G1.

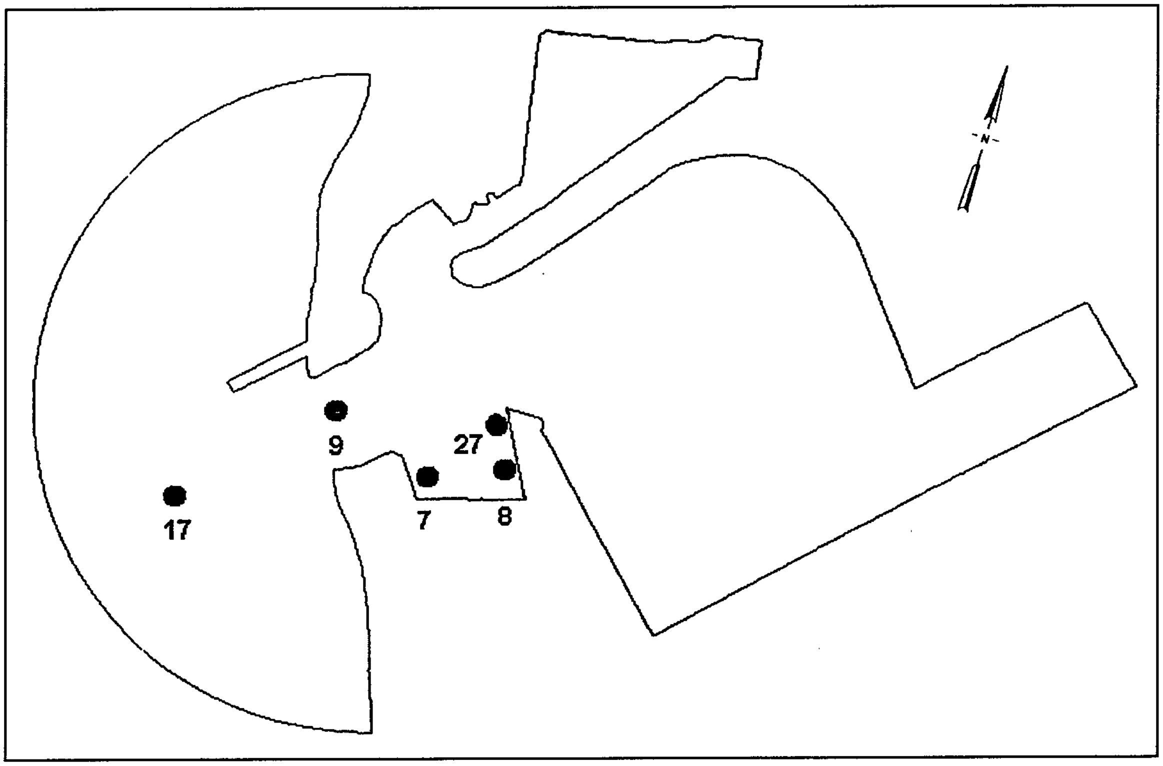

Figure G1. Numerical model output station locations

Mean significant wave height, $\bar{H}_s$, and maximum significant wave height, $H_{s,max}$, were also calculated for each point (Figures G2 throughG7, and Table G1). Barge basin $\bar{H}_s$ variation with direction shows a maximum for waves approaching the entrance from the west (270 deg). $\bar{H}_s$ for waves from the west in Plan 4c is slightly lower than in the existing harbor, indicating that the jetty is providing some shelter to the barge basin. For waves coming from south of approximately 240 deg, $\bar{H}_s$ in Plan 4c exceeds $\bar{H}_s$ in Plan 1a, indicating the deeper channel impacts barge basin wave conditions. Overall barge basin $\bar{H}_s$ is the same for both Plan 4c and existing harbors.

The $H_{s,max}$ is more variable, but tends to follow a similar trend. Maximum values in the barge basin corners are lower in Plan 4c than in Plan 1a since the maximum wave approached from the west was partially blocked by the jetty.

The standard Corps criterion for an acceptable mooring area is that H_s should not exceed 0.3 m (1 ft) more than 10 percent of the time. The barge basin was evaluated relative to this criterion (Table G2). Corner areas met the criterion in

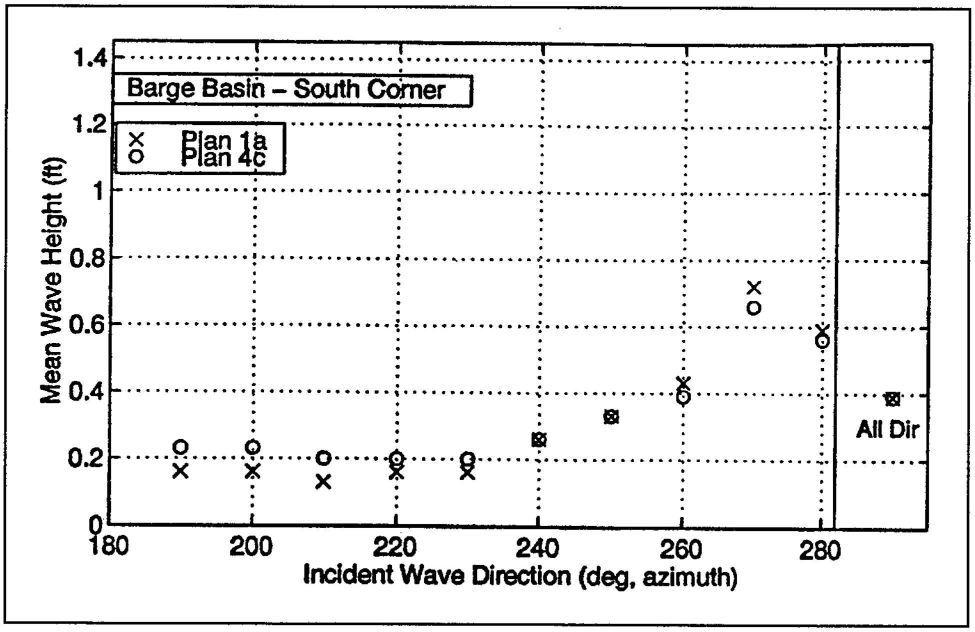

Figure G2. Mean H_s from HARBD, barge basin south corner, Station 7

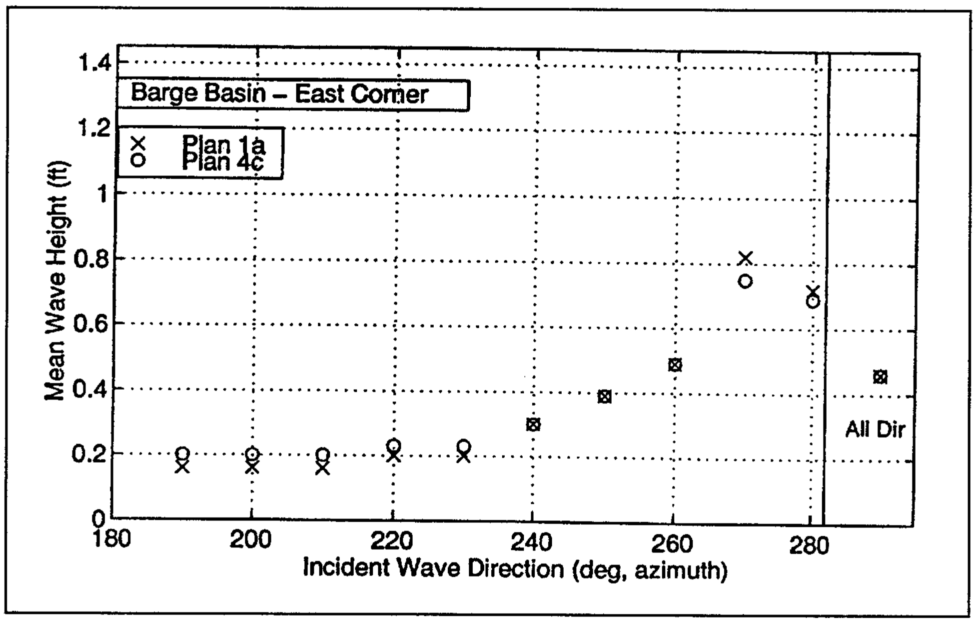

Figure G3. Mean H_s from HARBD, barge basin east corner, Station 8

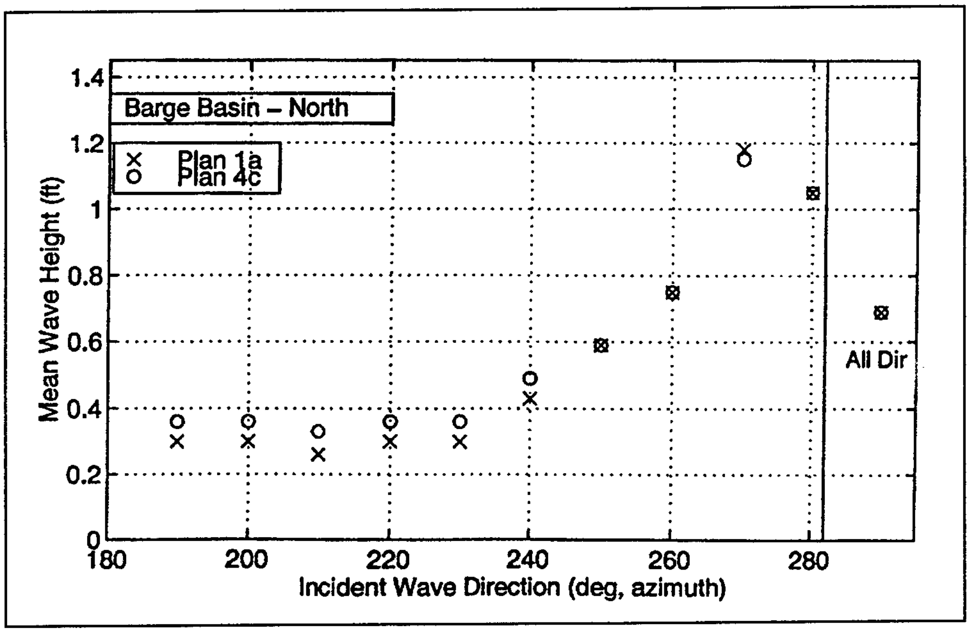

Figure G4. Mean H_s from HARBD, barge basin north, Station 27

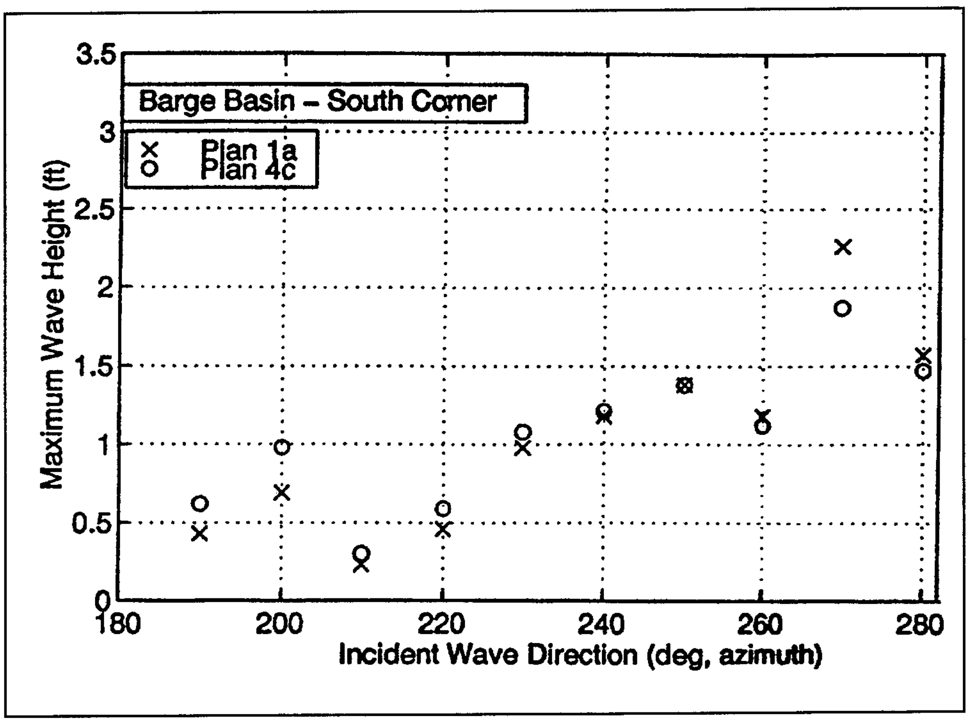

Figure G5. Mean H_s from HARBD, barge basin south corner, Station 7

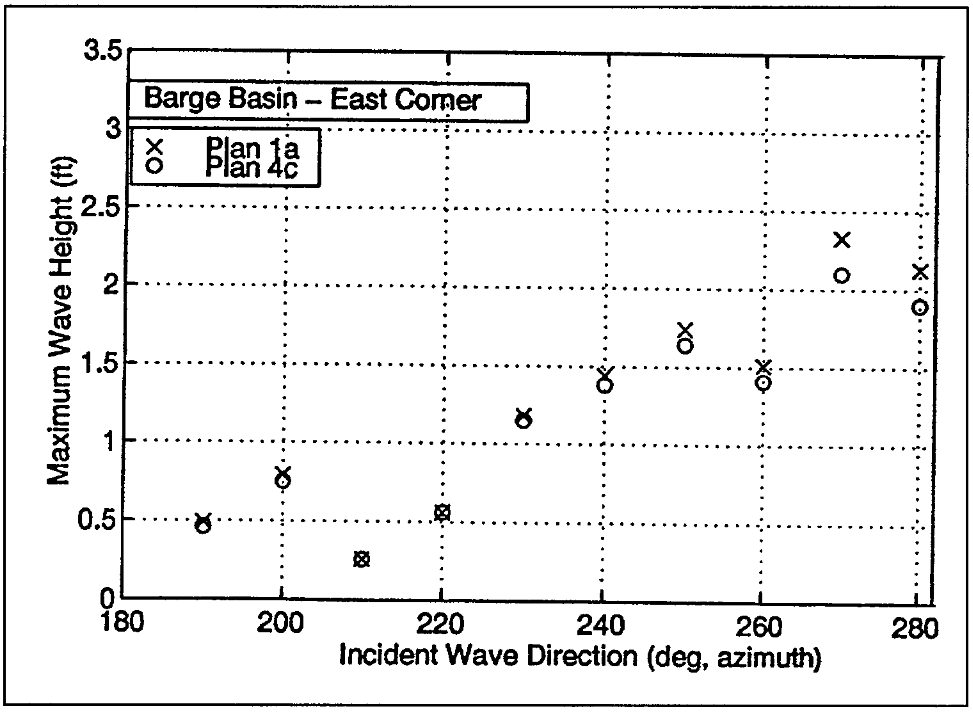

Figure G6. Mean H_s from HARBD, barge basin east corner, Station 8

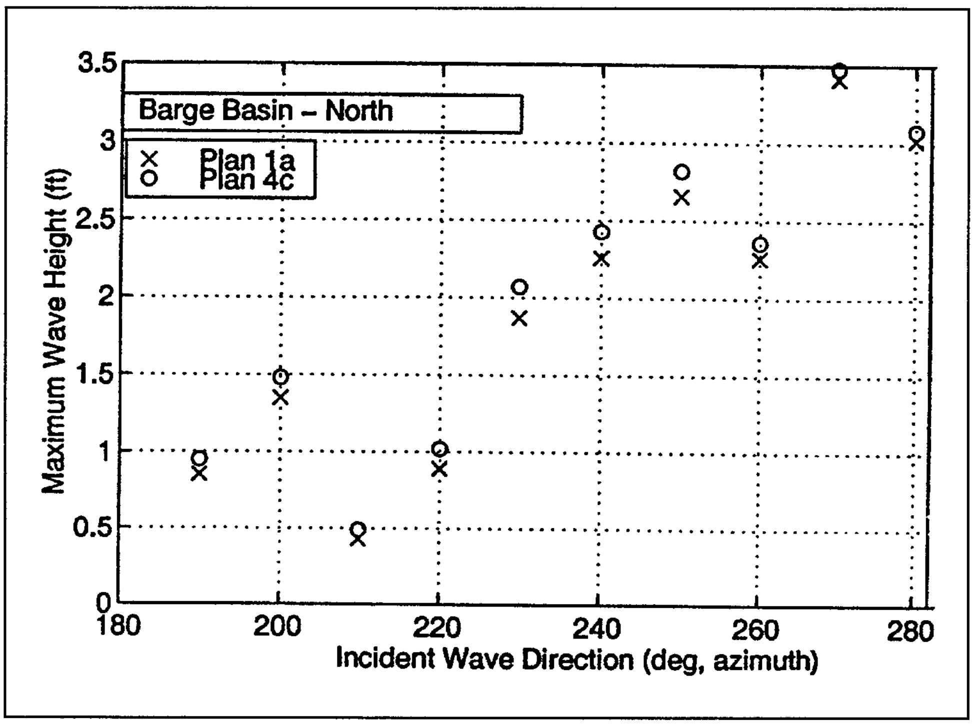

Figure G7. Mean H_s from HARBD, barge basin north, Station 27

both plans, with Plan 4c showing a small improvement over Plan 1a. The more exposed barge north location failed to meet the criterion in both plans.

Table G1
Mean and Maximum H_s, Based on Numerical Modeling

Location	Station	Mean H_s, ft		Maximum H_s, ft	
		Plan 1a	Plan 4c	Plan 1a	Plan 4c
Channel, 500 ft seaward of jetty tip	17	1.57	1.77	5.8	6.6
Channel, beginning of confined entrance	9	1.28	1.31	6.2	5.4
Barge basin, north	27	0.69	0.69	3.4	3.5
Barge basin, east corner	8	0.46	0.46	2.3	2.1
Barge basin, south corner	7	0.39	0.39	2.3	1.9

Table G2
Percent Occurrence of H_s Greater than 0.3 m (1 ft), Based on Numerical Modeling

Location	Percent H_s > 0.3 m (1ft)	
	Plan 1a	Plan 4c
Barge basin north, Station 27	16.5	16.5
Barge basin east corner, Station 8	6.6	5.8
Barge basin south corner, Station 7	5.0	3.5

Storm Waves in Barge Basin

Physical model experiments

A total of 44 wave cases from the previous physical model study[1] were analyzed to assess the impact of Plan 4c relative to Plan 1a on storm waves in the barge basin. Physical model wave gauges in the barge basin were positioned in the north part and in the south corner (Stations 27 and 7 in Figure G1). In Plan 1a, Station 27 is directly exposed to waves from 241- to 276-deg azimuth, an arc of 35 deg that includes waves from the west. In Plan 4c, waves approaching more northwesterly than 260-deg azimuth are partially blocked by the jetty.

[1] Briggs, M., Lillycrop, L., Harkins, G., Thompson, E., and Green, D. (1994). "Physical and numerical model studies of Barbers Point Harbor," Technical Report CERC-94-14, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

The 44 wave conditions analyzed included eight measured field conditions and 36 empirical wave cases. Selection criteria for the eight field cases (*BPS* series in Briggs et al. 1994[1]) included the following:

a. Obtaining the largest wave heights and a representative range of wave period and direction within model constraints.

b. Preference given to time after marina opened in July 1989 and second S_{xy} directional gauge installed.

c. Maximum number of operational field gauges for comparisons.

The eight field cases had peak wave periods ranging from 6 to 18 sec, significant heights ranging from 2.1 m (7 ft) to 3.0 m (0 ft), approach directions of 208- to 266-deg azimuth, and directional spreading up to 19 deg. All eight cases represent rare events because of their large wave heights. The water level for all experiments was mean lower low water (mllw).

The 36 empirical wave cases had periods of 7.7, 11.1, and 16.7 sec, significant height of 7.6 m (25 ft), and wave directions of 210-, 235-, and 270-deg azimuth. These cases were representative of very rare storm events because of their large wave heights. Half of the wave cases were directionally spread with a relatively wide spread of 10 deg (*BPD* series), and half were unidirectional with a narrow spread of 1 deg (*BPU* series). Both narrow- and wide-frequency spreading (i.e., $\gamma = 3.3$ and 7.0), representative of sea and swell, respectively, were also included. The water level included a storm surge and tide of 4.5 ft.

Thus, the 44 cases for physical modeling represent moderate to extreme storm wave heights and a representative range of wave periods, directions, and directional spreading. The eight field cases had significantly wider directional spread than any of the 36 empirical cases. Physical model wave heights are based on data sampling of each wave case for a prototype time of 5.7 hr (40 min model time). Reported wave heights are significant heights calculated from measured surface elevation time series.

Relative impacts of Plan 4c

Relative performance between Plan 4c and Plan 1a was assessed by comparing measured H_s values at the two barge basin wave gauges for each of the 44 wave cases. A value less than 1.0 (or 100 percent) indicates that Plan 4c gives reduced wind-wave energy in the barge basin, a desirable effect. Overall barge basin response is presented as an average of the two barge basin gauges

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[1] Briggs, M., Lillycrop, L., Harkins, G., Thompson, E., and Green, D. (1994). "Physical and numerical model studies of Barbers Point Harbor," Technical Report CERC-94-14, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

(numerical model station numbers are used to conveniently designate physical model gauge locations):

$$\text{Barge basin response} = 0.5 * \left(\frac{H_s \text{ Station 27, Plan 4c}}{H_s \text{ Station 27, Plan 1a}} + \frac{H_s \text{ Station 7, Plan 4c}}{H_s \text{ Station 7, Plan 1a}} \right)$$

The overall basin response indicates a reduction of storm wave height in Plan 4c relative to Plan 1a (Table G3). The impact of Plan 4c is small for the empirical cases but large for the field cases, possibly because of the large directional spread used in the field case simulations.

Table G3
Average Barge Basin H_s Response to Storms, Based on Physical Model Experiments

Experiment Series	Response[1] (percent)
Field cases	76
Directional empirical cases	93
Unidirectional empirical cases	95

[1] Average for Plan 4c divided by average for Plan 1a, converted to percent.

For the field experimental series, the lowest and highest H_s response ratios were 65 and 82 percent (Figure G8, and Table G4). The lowest case approached parallel to the entrance channel with relatively narrow directional spreading. The highest case approached the barge basin more directly and had wider directional spreading. The second lowest response was for a case with wave period of only 7.7 sec and approach direction of 218-deg azimuth, oblique to the barge basin.

For the directional and unidirectional empirical cases, the lowest and highest H_s response ratios were recorded by the same two cases. The lowest values were 73 and 82 percent for the directional and unidirectional cases, respectively (Figures G9 and G10 and Table G4). The highest values were 109 and 107 percent for the directional and unidirectional cases, respectively. The lowest case was for a relatively short wave period, narrow frequency spreading (i.e., $\gamma = 7.0$), and southerly wave direction (not directly into the barge basin). The highest case was for relatively long wave period, wide frequency spread (i.e., $\gamma = 3.3$), and westerly wave direction (directly into the barge basin). It appears that the barge basin response increases as wave period, frequency spreading, and barge basin exposure increase.

Differences between the field and empirical case groups can be attributed to several factors. Field cases are a small number of events that represent a limited sampling of conditions. Directional spreading in most field cases was

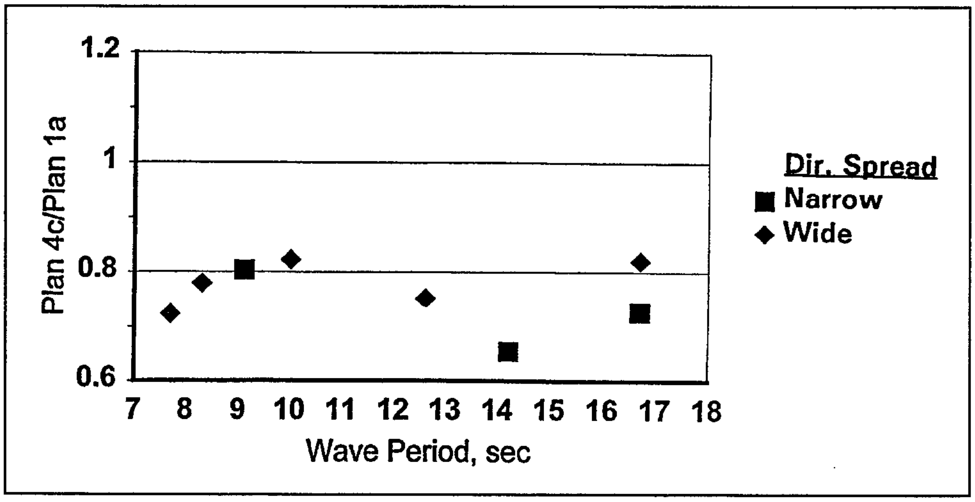

Figure G8. Physical model H_s ratios for field cases; directional spreads are narrow (7-9 deg) and wide 14-19)

Table G4
Physical Model Cases with Lowest and Highest Barge Basin Response

Case	(Plan 4c H_s) / (Plan 1a H_s) percent	H_s	T_p sec	θ, deg az.	Dir. spread deg	Freq. spread, γ
Field Cases						
Lowest	65	2.2 m (7.1 ft)	14.2	225	9	
Highest	82	2.3 m (7.4 ft)	10.0	243	16	
Empirical Cases						
Lowest:						
directional	73	7.6 m (25 ft)	7.7	210	10	77
unidirectional	82	7.6 m (25 ft)	7.7	210	1	
Highest:						
directional	109	7.6 m (25 ft)	16.7	270	10	3.3
unidirectional	107	7.6 m (25 ft)	16.7	270	1	3.3

significantly greater than even the directional empirical cases. A disproportionate number of field cases have wave approach directions nearly parallel to the channel (five out of eight field cases are within 10 deg of being parallel with the channel).

Physical model results also provide insight on variation of storm wave conditions across the barge basin (between the northeast and southwest areas). Differences between the two areas were investigated by computing the ratio of H_s for Plan 1a and Plan 4c at Station 27 and this ratio of H_s at Station 7. The average ratio for field cases is 1.71 in Plan 1a and 1.77 in Plan 4c, indicating that

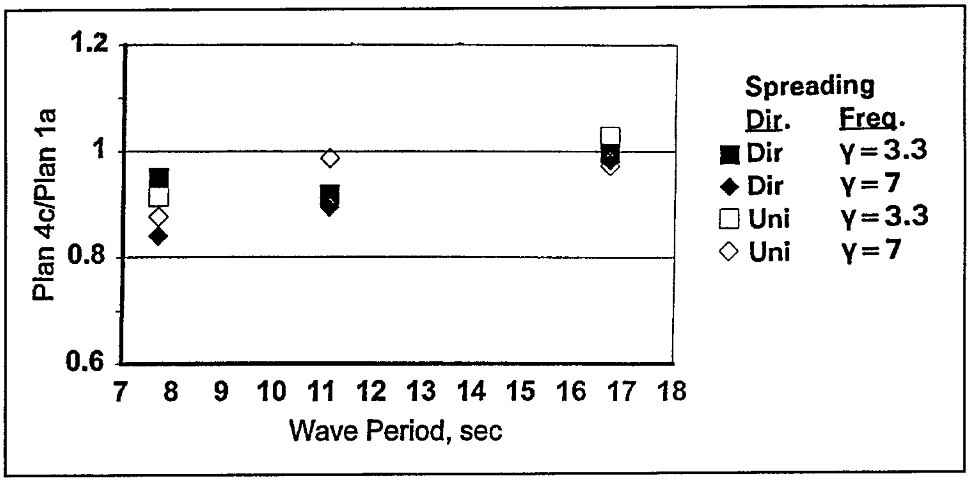

Figure G9. Physical model H_s ratios for empirical cases; effect of frequency and directional spreading, averaged over all approach directions

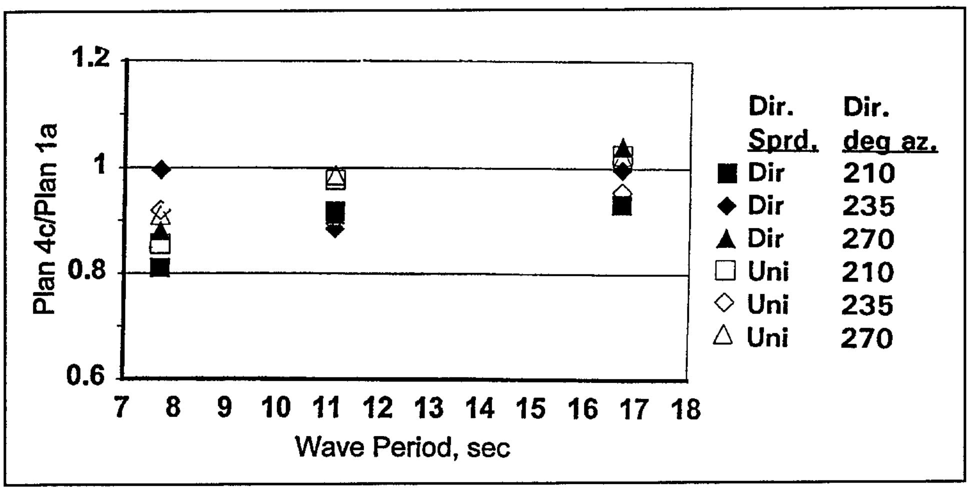

Figure G10. Physical model H_s ratios for empirical cases; effect of wave approach direction and directional spreading, averaged over all frequency spreadings

Station 27 tends to have significantly higher wave conditions than Station 7 for these storm events. In empirical studies representing very rare storms, average ratios for directional cases are 1.48 for Plan 1a and 1.47 for Plan 4c and for unidirectional cases are 1.33 for Plan 1a and 1.27 for Plan 4c. Thus, wave heights for extreme storm events become less variable over the barge basin. Considering that numerical model results showed a ratio of 1.77 between mean H_s values at Station 27 and Station 7 (Table G1), there is a clear tendency for wave-height differences across the barge basin to decrease when more extreme events "flood" the area with wave energy.

The deeper channel in Plan 4c tends to allow more wave energy to pass through the entrance to Barbers Point Harbor. However, the jetty helps to shelter the entrance, especially for waves approaching from the west or north of west. The net effect on mean significant wave height in the barge basin is no change from the existing harbor. Plan 4c provides a small improvement in protecting the barge basin from most storm waves.

Appendix H Plans 7a and 7b Harbor Oscillations[1]

Harbor oscillation studies of Barbers Point Harbor with a planned 183-m- (600- ft-) wide by 335-m- (1,100-ft-) long expansion were requested by the Pacific Ocean Division to document harbor response and ensure that the plan harbor is not prone to excessive long-period resonance. Two depth configurations were studied, based on physical model experiment results (Table H1).

Table H1
Barbers Point Harbor Plans 7a and 7b

	Entrance Channel		
Plan	Width	Depth	Deep-Draft Harbor Depth
7a	140 m (450 ft)	13.4 m (44 ft)	12.8 m (42 ft)
7b	140 m (450 ft)	14.3 m (47 ft)	13.7 m (45 ft)

Approach

Harbor oscillation studies were performed with the numerical model HARBD. The model was calibrated to field measurements in previous studies of Barbers Point Harbor (Briggs et al. 1994). Also, the model was used previously to study oscillations in other plan configurations for the harbor. The intent in this study was to use the calibrated model to study the new Plans 7a and 7b configurations. The U.S. Army Engineer Waterways Experiment Station has gained considerable experience and understanding of HARBD since the previous studies were performed. Experience has been obtained from both basic experiments with idealized harbors and practical experience with other harbor studies accompanied by field measurements, including Kaumalapau Harbor, Lanai, and

[1] Appendix H was prepared by Dr. Edward F. Thompson and Mr. Doyle L. Jones.

Kahului Harbor, Maui (Smith 1998; Thompson et al. 1996). Based on these experiences, it was evident that some parameter settings used in the earlier Barbers Point Harbor numerical model study should be modified for best results.

The numerical model grid for the existing Barbers Point Harbor developed by Briggs et al. (1994) was used in this study to recalibrate with revised parameter settings. Field data described by Briggs et al. (1994) and Lillycrop et al. (1993) were again used for calibration. Parameters for the recalibrated numerical model are given in Table H2. Key differences in this study include a constant bottom friction value and a harbor boundary reflection coefficient less than 1.0.

Table H2
Parameter Values Used in HARBD

Parameter	Value
Bottom friction, β	0.032
Coastline reflection, $K_{r,coast}$	1.0
Depth in infinite region, d_{far}	8.5 m (28.0 ft)
Harbor boundary reflection, K_r (wave periods of 25-100 sec)	0.95
Harbor boundary reflection, K_r (wave periods > 100 sec)	0.96

Finite element numerical grids representing Plans 7a and 7b were developed by modifying the Plan 4c grid used previously. Modifications include reducing the size of the harbor expansion to 183 m (600 ft) by 335 m (1,100 ft), moving the channel/harbor depth transition to the area where the channel opens into the harbor basin (as recommended from physical model studies), and modifying project depths as in Table H1. Plan 7a and 7b grids are similar except for project depths imposed in the harbor and entrance channel. Grid characteristics are summarized in Table H3.

Table H3
Grid Size

	Number of:			
Harbor Plan	Elements	Nodes	Solid Boundary Nodes	Semicircle Boundary Nodes
7a, 7b	12,501	6,603	592	112

Wave periods ranging from 25 to 1,000 sec were modeled using parameter settings derived by recalibration (Table H2). Incident long wave height was 0.06 m (0.2 ft), representing a realistic long wave event, and approach direction was approximately perpendicular to shore. Harbor response information was saved at 32 station locations (Figure H1).

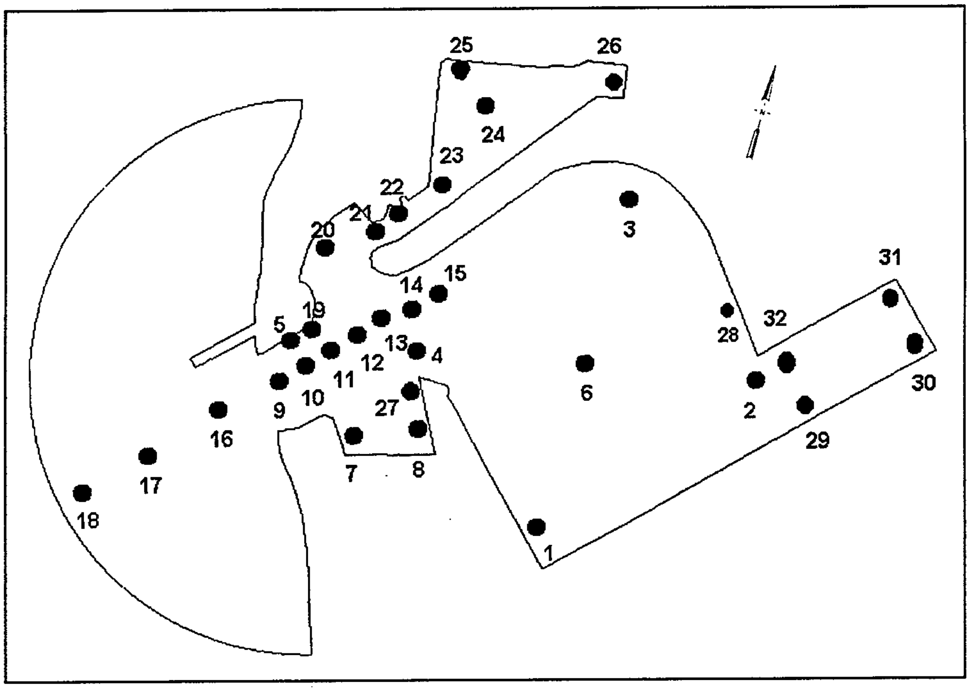

Figure H1. Output station locations

Results

Harbor oscillation results are summarized as amplification factor versus wave-frequency plots for each station. Amplification factor is defined as long wave amplitude at the station location divided by incident long wave amplitude. Plots for representative stations in the deep-draft harbor, barge basin, and channel are included in this report (Figures H2-H15). Plans 7a and 7b, included together in the plots, had very similar responses. Resonant peaks in Plan 7b were shifted to slightly higher frequencies relative to Plan 7a because of the deeper project depths.

Except for very low frequencies at which the entire harbor rises and falls in unison (frequencies less than 0.002 Hz; periods longer than 500 sec), amplification factors in the channel and main harbor (Stations 1-6 and 28) are nearly all less than 2.0, with a maximum of 3.0. In the deep-draft harbor expansion area (Stations 29-32), a tendency for stronger amplifications is evident. Corner Stations 30 and 31 are most active, though maximum amplification factors are still around 3.0 or less. Barge basin corners (Stations 7 and 8) are more active than the deep-draft harbor. Amplification factors exceed 3.0 for several peaks, but are always less than 4.0.

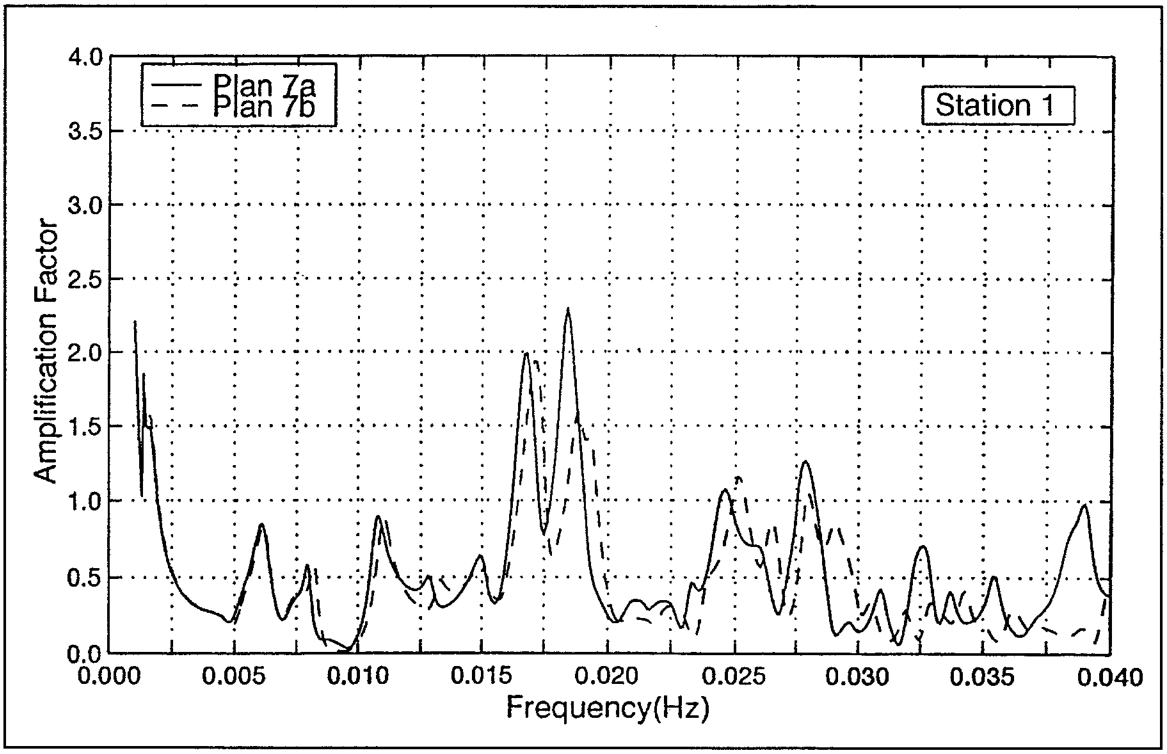

Figure H2. Wave amplification factors, Station 1

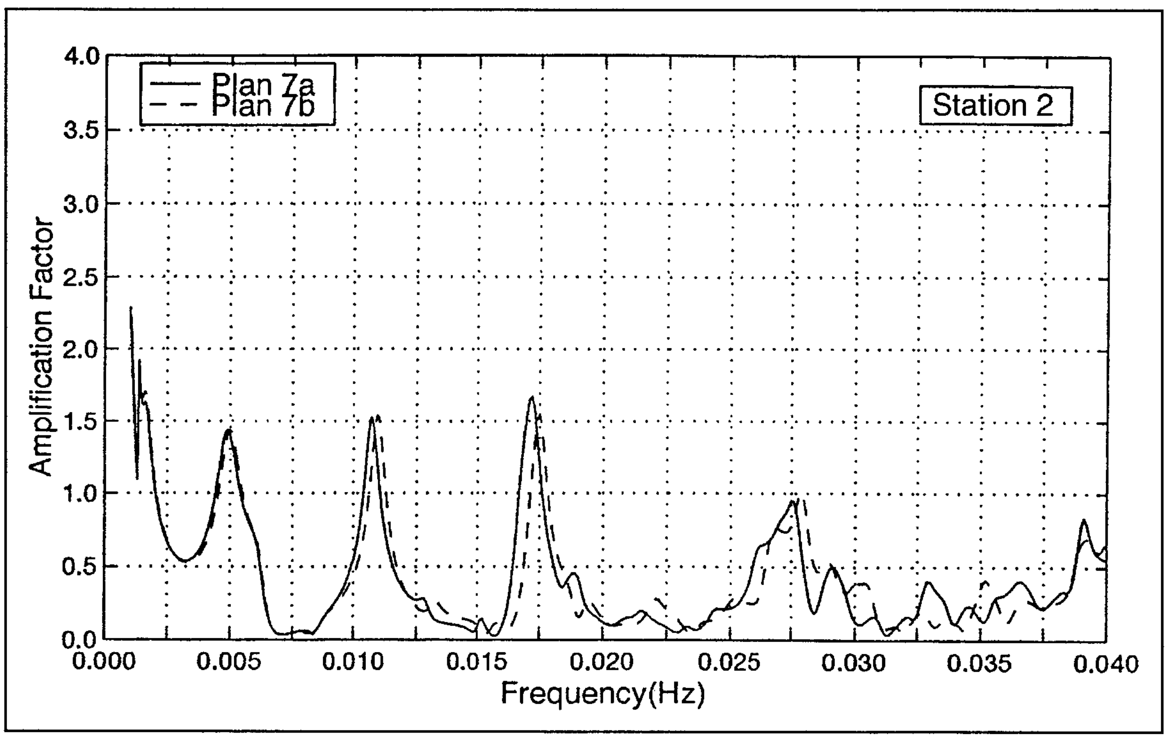

Figure H3. Wave amplification factors, Station 2

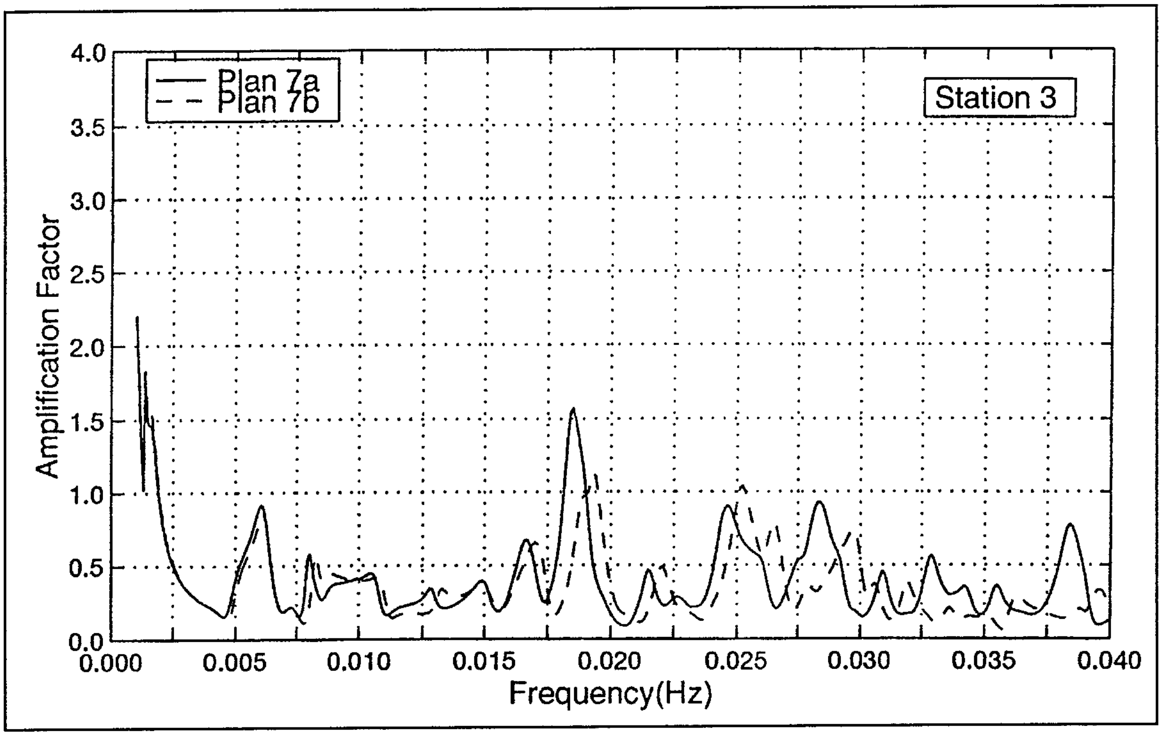

Figure H4. Wave amplification factors, Station 3

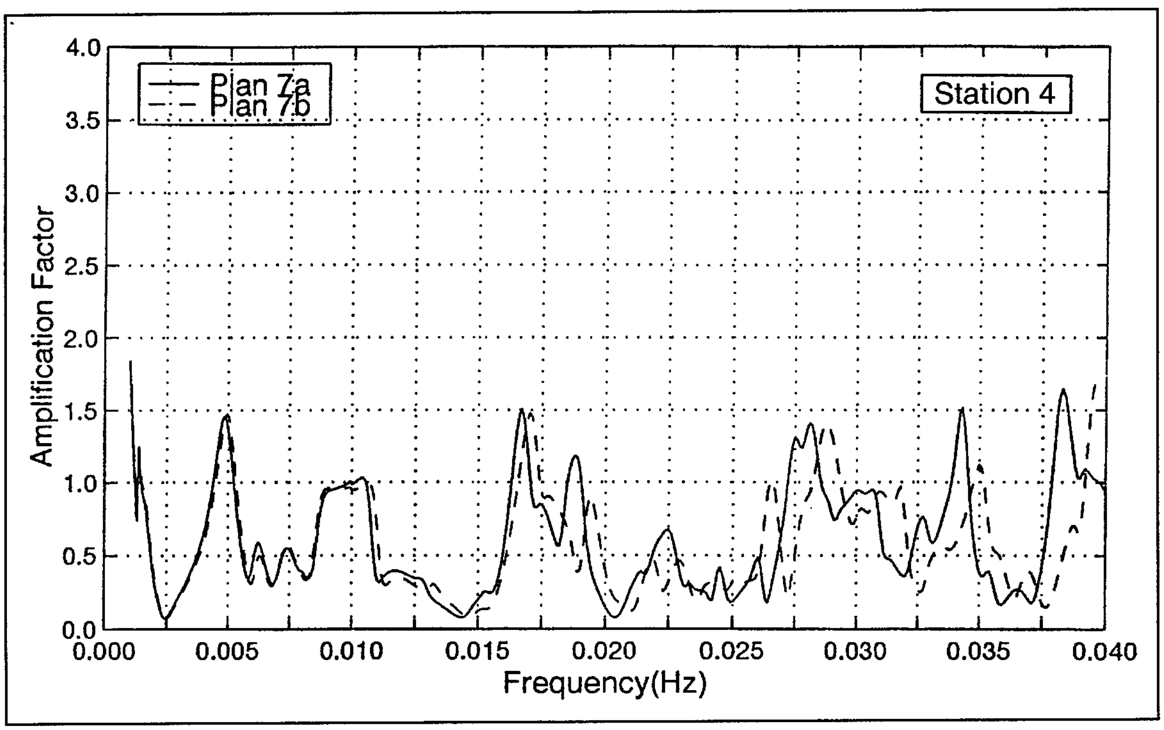

Figure H5. Wave amplification factors, Station 4

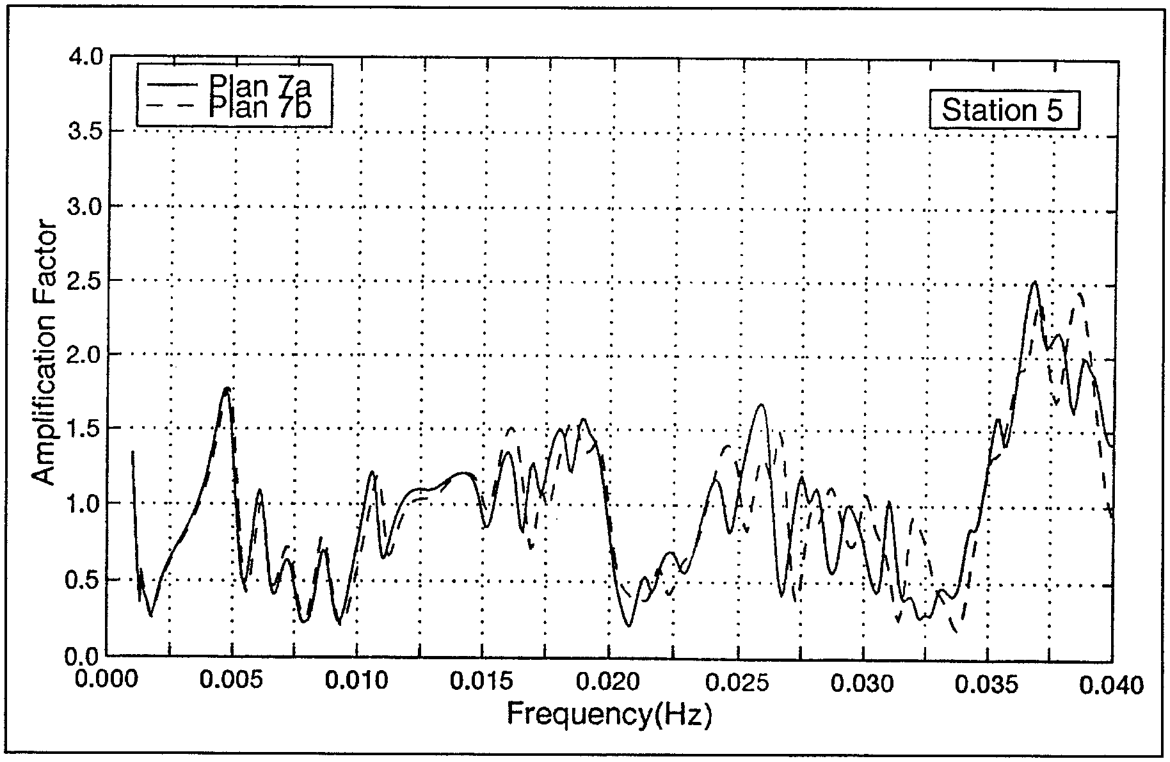

Figure H6. Wave amplification factors, Station 5

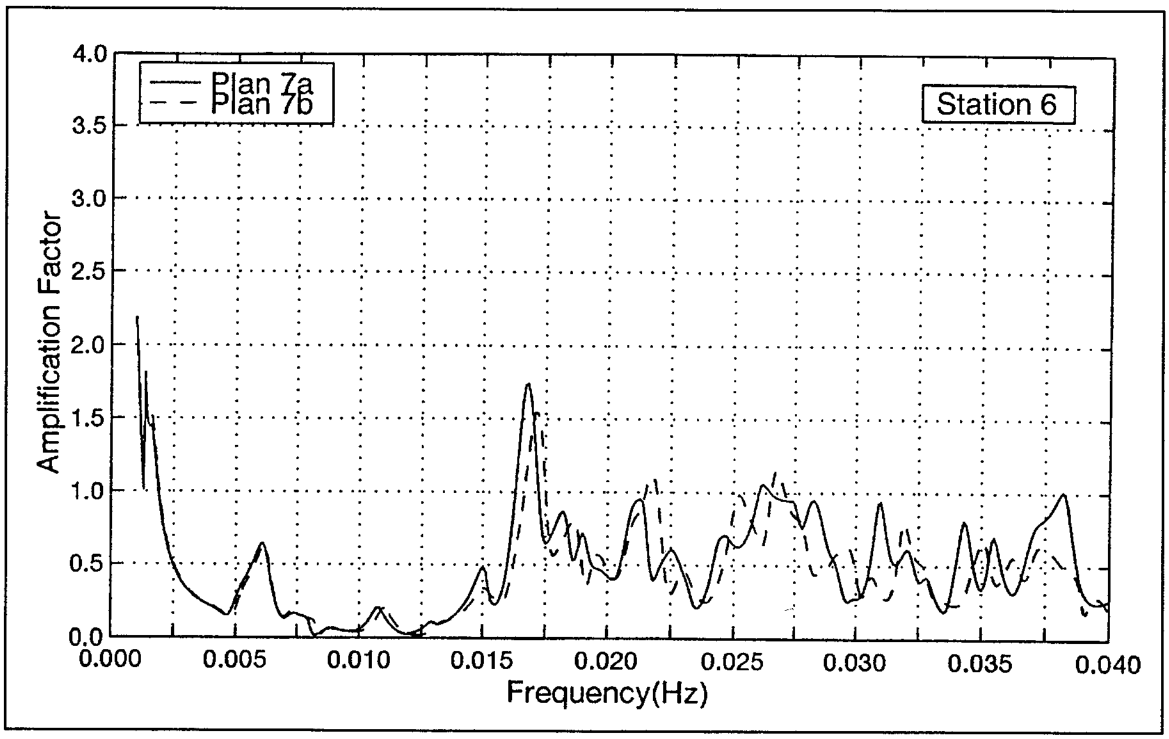

Figure H7. Wave amplification factors, Station 6

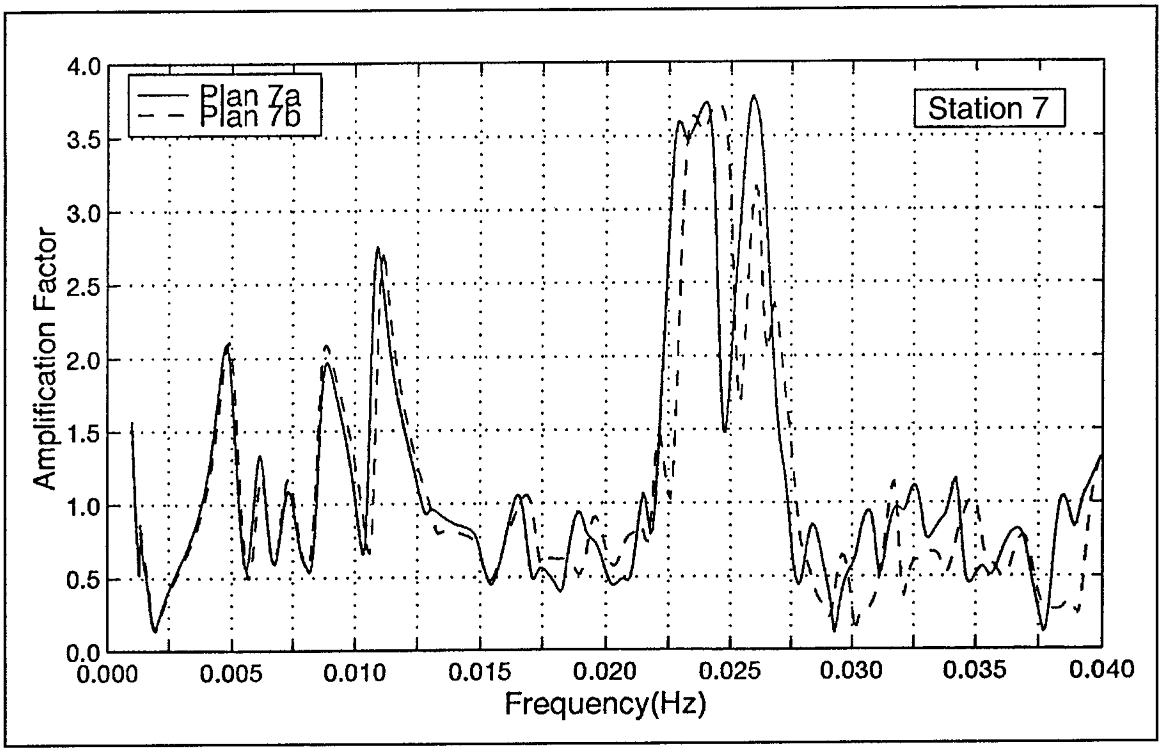

Figure H8. Wave amplification factors, Station 7

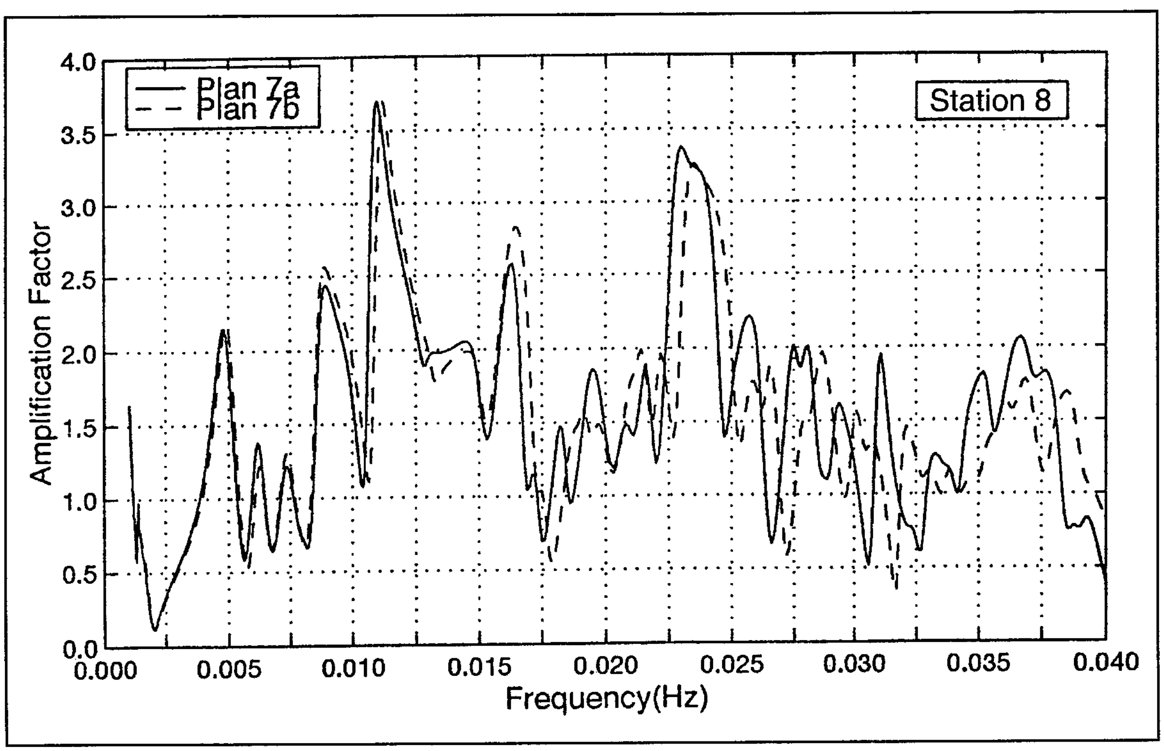

Figure H9. Wave amplification factors, Station 8

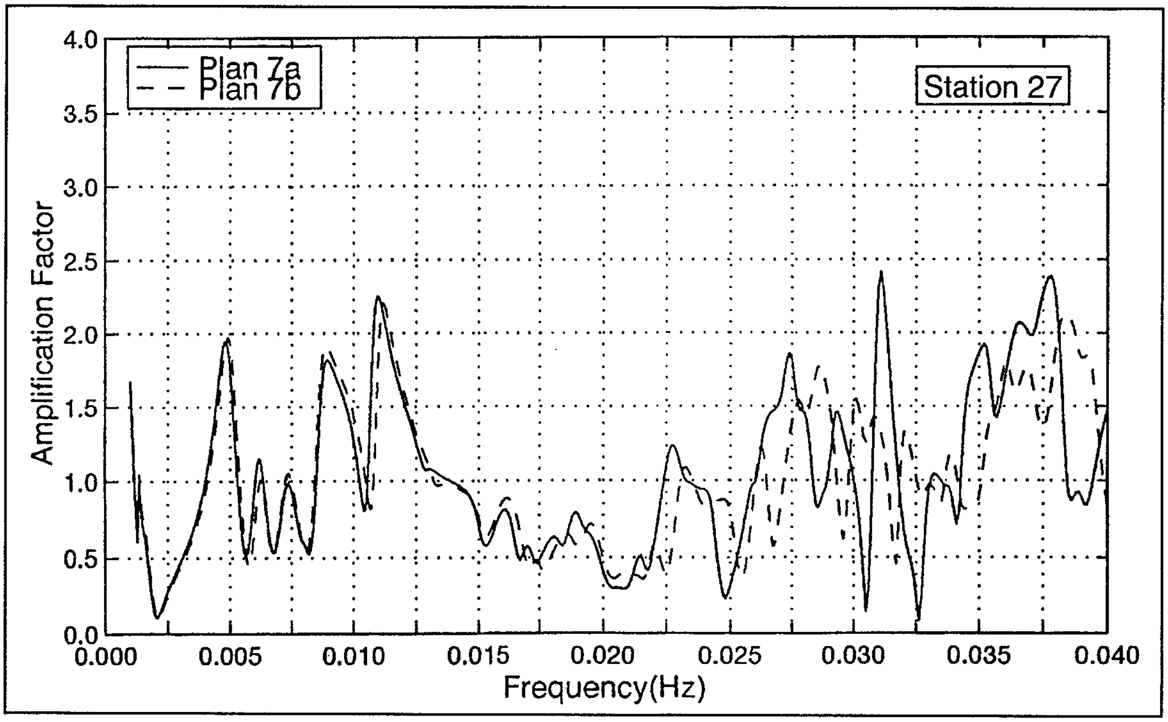

Figure H10. Wave amplification factors, Station 27

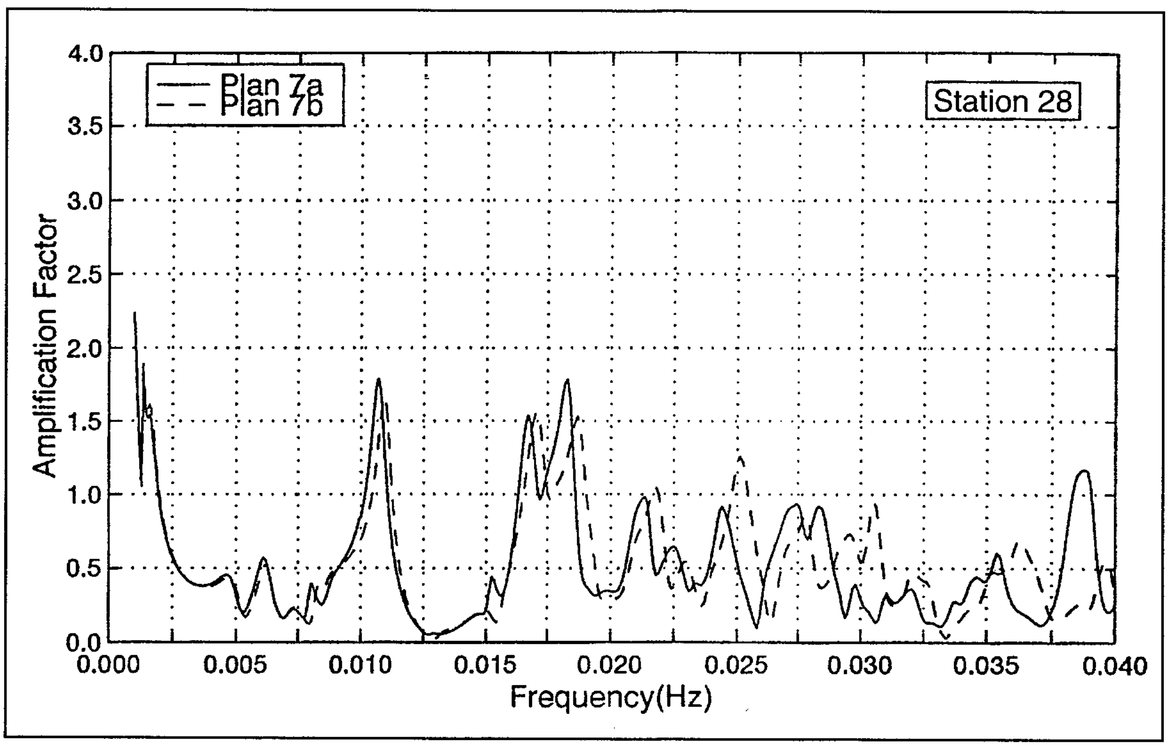

Figure H11. Wave amplification factors, Station 28

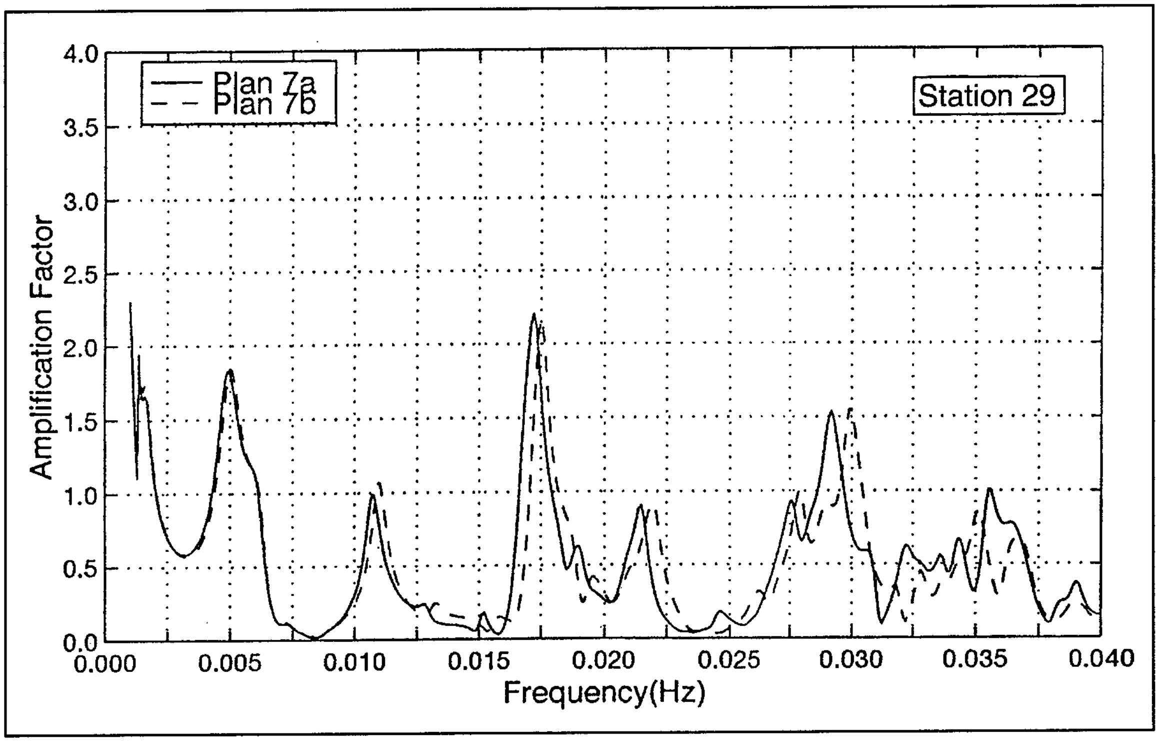

Figure H12. Wave amplification factors, Station 29

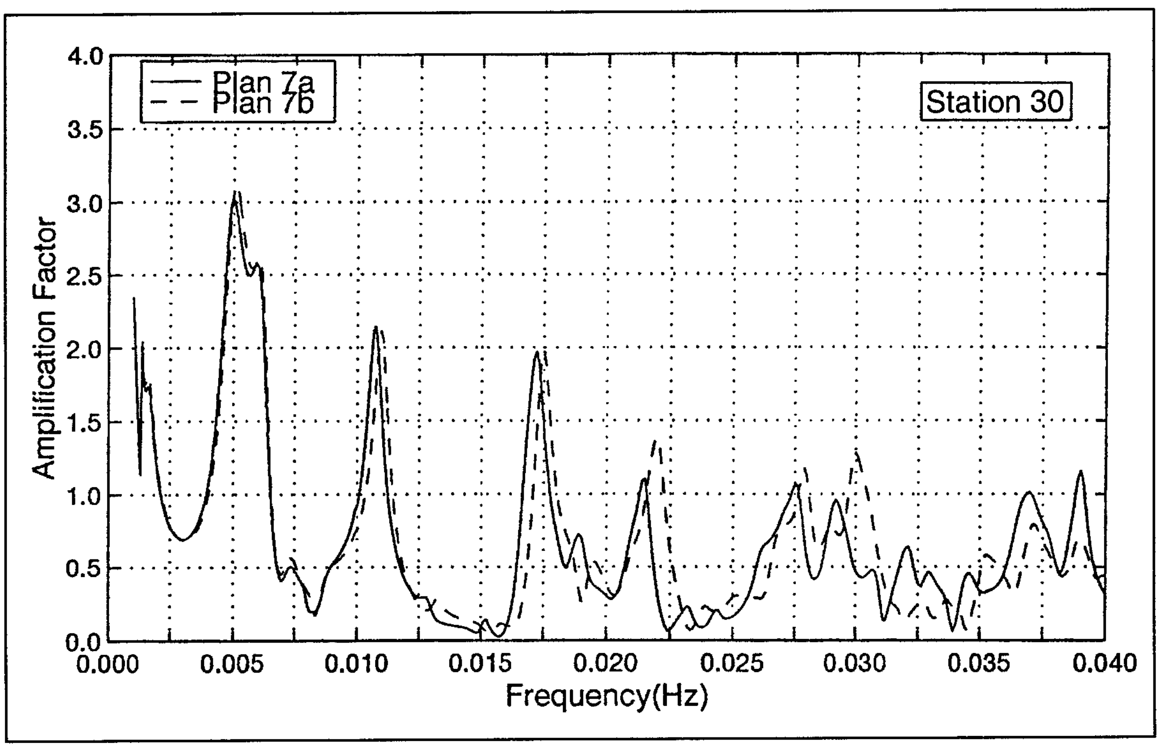

Figure H13. Wave amplification factors, Station 30

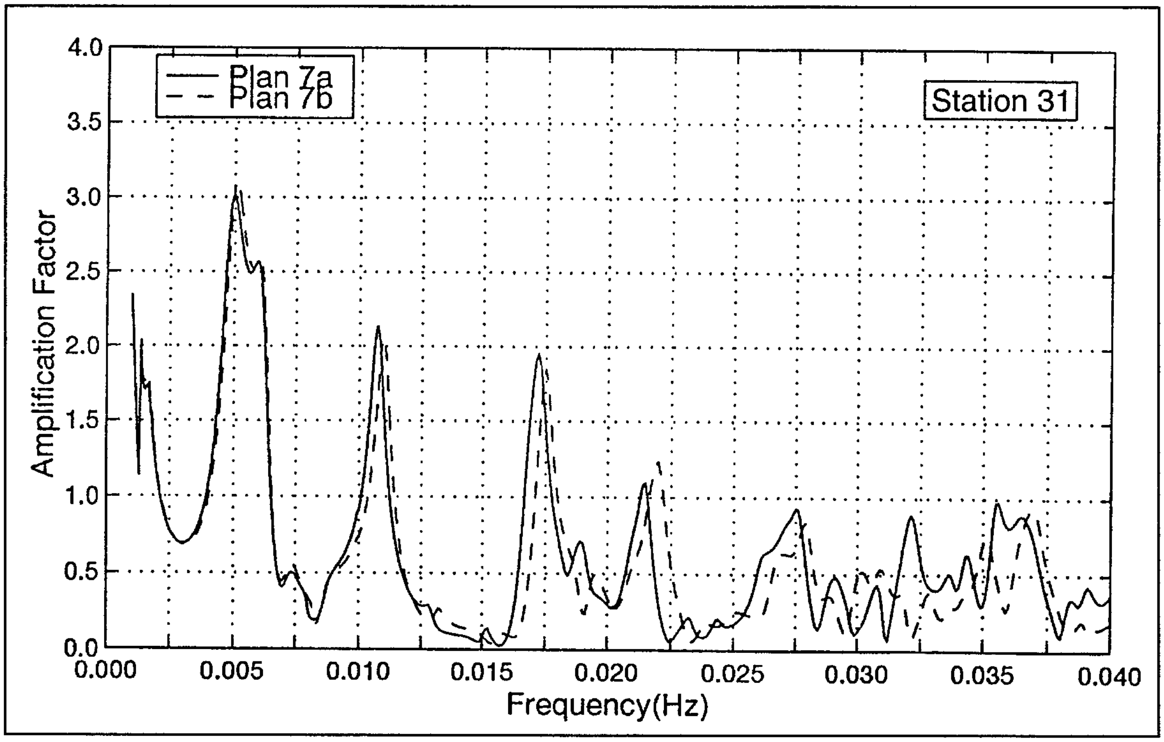

Figure H14. Wave amplification factors, Station 31

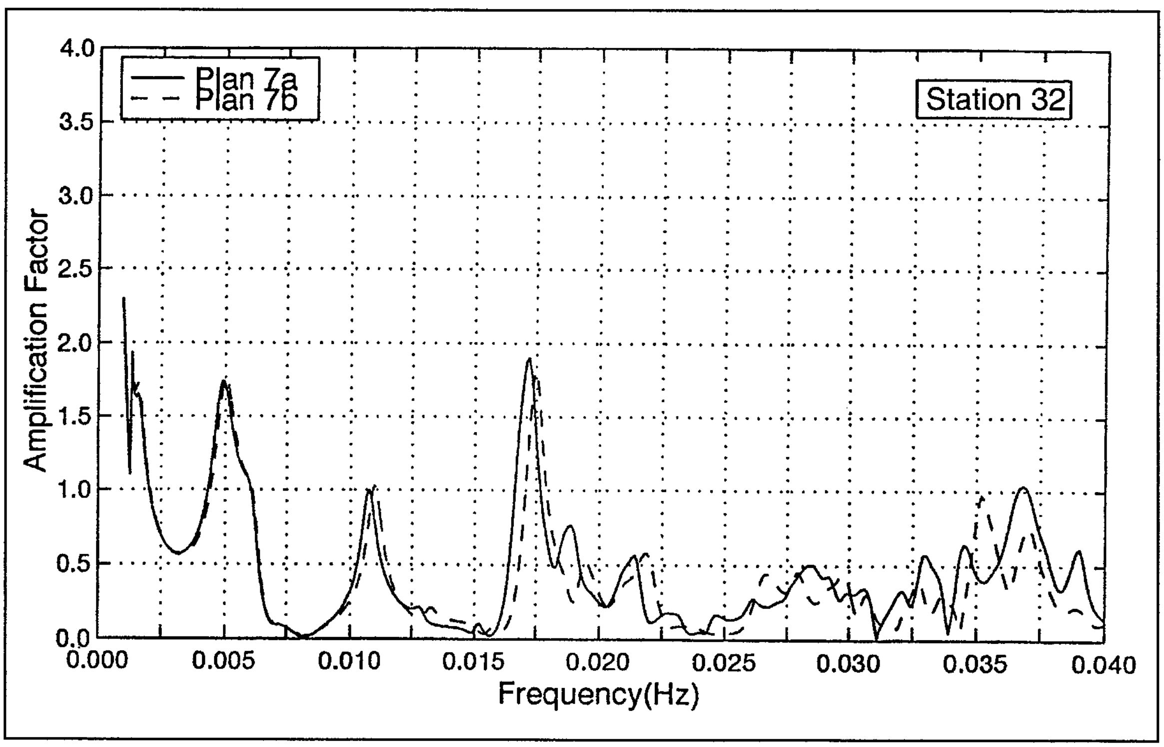

Figure H15. Wave amplification factors, Station 32

Past experience with physical and numerical modeling of harbor oscillations suggests the following:

a. If the amplification factor near a pier at any relevant long wave period is greater than 5, some operational difficulties may be encountered.

b. If the amplification factor is greater than 10, major operational difficulties can be expected.

By these criteria, the channel, the deep-draft harbor, and the barge basin in Plans 7a and 7b are not prone to excessive long-period resonance. A recent analysis of long wave velocities in Barbers Point Harbor with 335-m (1,100-ft) by 335-m (1,100-ft) expansion (Plan 4c) shows a high-energy long wave event may produce velocities of over 0.5 m/sec (1 knot) adjacent to the expansion corner where it opens into the main harbor basin (Thompson, Boc, and Nunes 1998). These localized velocities may be a concern in Plans 7a and 7b.

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13. ABSTRACT *(Maximum 200 words)*

Barbers Point Harbor, Hawaii, is located on the southwest coastline of Oahu. The present harbor complex consists of an entrance channel, deep-draft harbor, barge basin, and a private resort marina. Current and potential future users of the harbor would like the capability for fully loaded vessels to enter and leave the harbor, but safe vessel draft is restricted by existing harbor and entrance-channel depths. For a vessel to enter and leave the harbor, there must be a safe distance between the bottom of the vessel keel and the ocean bottom (underkeel clearance). The two fully loaded design vessels (modified Bunga Saga Empat bulk-cargo carrier and APL C-9-class containership) used in this study could not enter and leave the now-existing harbor configuration safely.

Presently, the State of Hawaii Department of Transportation (HDOT) is using a 0.6-m (2-ft) underkeel clearance criterion in the harbor that translates to a 1.8-m (6-ft) underkeel clearance in the channel. The Corps of Engineers' Pacific Ocean Division (POD) criterion is more conservative, calling for a 1.2-m (4-ft) and 2.4-m (8-ft) underkeel clearance in the harbor and entrance channel, respectively. Objectives of this study were to determine the optimum vessel draft/entrance-channel depth combinations that can safely transit the entrance channel and harbor. Simulations of the two design vessels' transit through the entrance channel and into the harbor were made for selected wave conditions, and the underkeel clearance was measured.

(Continued)

14. SUBJECT TERMS

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Harbor expansions	Physical models
Harbor oscillations	Underkeel clearance
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POD also requested numerical investigations to (a) analyze impacts of the north jetty on wave climate in the barge basin and (b) document harbor-oscillation characteristics for a planned harbor expansion.

Based on analysis of physical model data, the following conclusions and recommendations are deduced:

a. The State HDOT underkeel criterion in the harbor does not allow enough clearance for the design vessels to transit into the harbor without possible groundings.

b. The State HDOT and Corps POD criteria in the channel are both conservative, and no groundings or near groundings were found.

c. The recommended underkeel clearance is 0.9 m (3 ft) in the harbor and 1.5 m (5 ft) in the channel for the design vessels studied and for waves less than 2.1 m (7 ft) in height.

d. The transition should be moved to the opening of the harbor basin. At the proposed transition location, there is less wave energy; if vessel shear occurs, the harbor pilot would have more room to react/correct. Model navigation study data support a 0.6-m (2-ft) transition.

Based on numerical investigations, the deeper channel in Plan 4c tends to allow more wave energy to pass through the entrance; however, the jetty helps to shelter the entrance, especially for waves approaching from the west or north of west. The net effect on mean significant wave height in the barge basin is no change from the existing harbor. Plan 4c provides a small improvement in protecting the barge basin from most storm waves. The channel, deep-draft harbor, and barge basin in Plans 7a and 7b are not prone to excessive long-period resonance. Another recent analysis of long-wave velocities for Plan 4c shows a high-energy long-wave event may produce velocities of over 0.5 m (1 knot) adjacent to the expansion corner where it opens into the main harbor. These localized velocities may be a concern in Plans 7a and 7b.